be equipped with a manual or automatic switch to select instantaneously between two sets of standards falling within the above ranges, one of which will be the present monochrome standards, and the other the CBS proposed standards. The receiver would produce pictures of equivalent size, geometrical linearity and brightness on each of the two positions of the switch. Interested persons are given until September 29, 1950 to submit comments. In addition, manufacturers are requested to submit a statement as to whether if the bracket standards are adopted they would, commencing with the effective date of the order adopting the bracket standards as final--30 days after publication of the order in the Federal Register--build all their television receivers so as to be capable of operating within the above brackets. If, on the basis of the comments submitted, the Commission is able to adopt the bracket standards as final without a hearing and if the Commission receives assurances from a sufficient number of manufacturers to insure that such bracket standards will be incorporated in the great majority of television receivers, then we will be in a position to postpone a decision in this proceeding since we will have the time to explore more fully the matters set forth above, confident in the knowledge that adequate provision has been made to prevent aggravation of the compatibility question. If the bracket standards cannot be made final without a hearing or if assurances are not received from a sufficient number of manufacturers concerning their plans for incorporating bracket standards in their receivers, the Commission will not feel free to postpone a decision, for every day that passes would aggravate the compatibility problem. In that event, a final decision would be issued adopting the CBS color standards."

3. The amendments proposed by this Notice provide for bracket standards as follows:

a. The scanning line frequency shall be within the bracket 15,000 to 32,000 per second.*

b. The field frequency shall be within the bracket 50 to 150 per second.*

* Until further order, television stations shall utilize the following standards: - the number of scanning lines shall be 15,750 per second, and the number of fields shall be 60 per second.

In other respects the transmission standards would not be changed by this Notice.

4. On or before September 29, 1950, any interested person who is of the opinion that the amendments proposed in paragraph 3 of this Notice should or should not be adopted, or should not be adopted in the form set forth, may file a written statement setting forth his comments or proposed amendments.

5. All manufacturers of television receivers are requested by the Commission to submit comments in accordance with paragraph 4 of this Notice, and to include in such comments an affirmative statement as to whether such manufacturers would, commencing with the effective date of the adoption of bracket standards*, design and manufacture all their television receivers so that:

(a) Such receivers would be capable of operating within the brackets set forth in paragraph 3 of this Notice,

(b) Such receivers would be equipped with a manual or automatic switch so as to be able to select one of the following two sets of standards:

(i) 15,750 lines per second and 60 fields per second.

(ii) 29,160 lines per second and 144 fields per second.

(c) Such receivers would be capable of producing monochrome pictures of equivalent size, geometric linearity and brightness on each of the above two sets of standards.

PROPOSED

6. In accordance with Section 1.754 of the Commission's Rules and Regulations, an original and 14 copies of such written statement shall be filed with the Commission.

7. Authority to issue the proposals herein is vested in the Commission by Sections 4(i), 301, 303(a),(b), (c), (d), (e), (f), (g), (h) and (r) of the Communications Act of 1934, as amended.

FEDERAL COMMUNICATIONS COMMISSION

T. J. Slowie
Secretary

* An order of the Commission adopting the bracket standards would become effective 30 days after its publication in the Federal Register.

Adopted: September 1, 1950

Released: September 1, 1950

[fols. 295-296] EXHIBIT "D" TO COMPLAINT

BEFORE THE FEDERAL COMMUNICATIONS COMMISSION, WASHINGTON, D. C.

IN THE MATTERS OF

Docket Nos. 8736 and 8975

AMENDMENT OF SECTION 3.606 OF THE COMMISSION'S RULES AND REGULATIONS

Docket No. 9175

AMENDMENT OF THE COMMISSION'S RULES, REGULATIONS AND ENGINEERING STANDARDS CONCERNING THE TELEVISION BROADCAST SERVICE

Docket No. 8976

UTILIZATION OF FREQUENCIES IN THE BAND 470 TO 890 MCS. FOR TELEVISION BROADCASTING

COMMENTS OF RADIO CORPORATION OF AMERICA

September 28, 1950

[fol. 297] CONTENTS

Annex E

[fol. 299] Radio Corporation of America (RCA) submits herewith its comments with respect to the Second Notice of Further Proposed Rule Making released September 1, 1950 (FCC 50-1065).

The Commission's Notice requests comments regarding a proposed change in the black and white television standards. It is clear from the Notice, and the Report on Color Television upon which the Notice is based, that the major reason for the proposed change is the Commission's attempt to make possible the adoption of the incompatible low-definition CBS color system. The first part of these [fol. 300] comments is addressed to this purely color reason for the proposed change in the black and white standards.

The Commission's Proposed Change in Black and White Standards is Based upon Fundamental Error

RCA believes the First Report is wrong

In the opinion of our engineers the Commission's decision is scientifically incorrect. RCA will continue research, development and improvement of its compatible, all-electronic, high definition color system notwithstanding the First Report of the Commission.

RCA does not propose to adopt the attitude of CBS in the 1946 hearing, where CBS stated that if its system were not adopted CBS would quit research in color.

We expect to continue to broadcast color signals under the RCA system and to use every scientific resource at our command to further the progress of color. We cannot acquiesce in a decision with respect to difficult scientific questions where the professional judgment of practically the entire industry is united that the public is about to be saddled with an inferior system. We believe that such a decision would violate the Commission's obligations under the law and would deny the public, the broadcasters and the manufacturers their rights under the law.

Where as here we have a conflict between the learned

scientists comprising the Condon Committee* and the mem-[fol. 301] bers of the Commission, that conflict should be resolved by the jury which is going to have to live under the color system adopted. That jury is the American people. In view of the situation in which the Commission now finds itself, the Commission should permit the broadcast of color signals under both the CBS and the RCA systems for a reasonable period of time before adopting final standards. We await the verdict of the public with confidence. No matter what it is we shall abide by it.

The Commission completely disregards the interests of the 10,000,000 or more American families who will own present models of black-and-white receivers by the end of this year. These 10,000,000 families represent an audience of 40,000,000 or more people.

The Commission's Report clearly shows that the Commission itself is not satisfied with the CBS system and that the CBS system is inadequate. Yet the Commission threatens to adopt the CBS system now unless the industry will yield to impossible and illegal conditions.

The Commission's Report shows that it is based on scientific errors, and that the Commission admittedly does not understand the RCA all-electronic, high-definition, compatible color system. The Commission has the obligation to inform itself as to the basic principles of this system and the superior performance which they make possible.

The adoption of bracket standards is unnecessary, costly and contrary to the public interest. The adoption of bracket standards is obviously a make-shift compromise proposal, serving perhaps to obtain unanimity within the Commission, but failing to serve the public interest.

[fol. 302] It would be difficult to over-emphasize the importance of the issue before the Commission. It is faced with the adoption of standards which should last for dec-

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* This Committee was headed by the Director of the National Bureau of Standards and was organized to give the Senate Committee on Interstate and Foreign Commerce "sound, impartial, scientific advice" on color television. The Committee was "a small group of scientific persons of repute, none of whom are employed by or have any connection directly or indirectly with any radio licensee or radio-equipment manufacturer".

ades. No question before the Commission so clearly calls for action in the long-range interest of the public.

A. The Commission Should Not Adopt a Color System With Which It is Not Satisfied

Preeminent among the reasons why RCA opposes the action of the Commission is a point of principle. That point of principle is that the Commission should not, merely in order to do something about color now, adopt a color system with which the Commission itself is not satisfied, and which is not in the public interest, convenience or necessity.

The Commission's Report clearly recognizes that compatibility, high resolution, large direct-view picture size, and other advantages of the RCA color television system are essential attributes of any color television system. Yet the Commission's Report would outlaw the RCA system in favor of the CBS system which has shown none of these attributes.

The Commission recognizes that the CBS system should not be adopted because it is not compatible—or the Commission would not propose "bracket standards" and seek to compel manufacturers to build receivers to accept degraded CBS standards as well as the present high-quality monochrome standards. The RCA system is completely compatible.

The Commission recognizes that the CBS system should not be adopted because of its degraded resolution—or the Commission would not desire more information as to the increased resolution obtainable with horizontal interlace [fol. 303] in the CBS system. Horizontal interlace is an integral part of the RCA system.

The Commission recognizes that the CBS system should not be adopted because of the picture-size limitations and other defects inherent in a disc-type mechanical system—or the Commission would not seek to postpone its decision until it can be assured that the system ultimately adopted shall be all-electronic and utilize the tri-color tube, developed and demonstrated on the record by RCA.

Faced with such a situation, where the Commission itself has such serious and valid objections to a system, the only course open to the Commission is to stay its hand.

The Commission's Report expresses doubts as to the

RCA system—doubts with respect to its color fidelity, the brightness of its receivers, and even its resolution. It is largely on the basis of such doubts that the RCA system has been put aside.

Conversely, while the Report clearly recognizes and the Notice is based upon the incompatibility, degraded resolution and other defects of the CBS system, the Report would nevertheless adopt that system on the "speculation and hope" that some of these defects—but not incompatibility—may in the future be overcome.

The public interest cannot be served by adopting an inferior system now, simply to be doing *something* now. Acting in favor of a ten year old incompatible system on the "speculation and hope" that a permanent ceiling will not have thus been placed on the progress of color television, rather than to give the new and superior system an opportunity to prove its potentialities, is unjustifiable.

[fol. 304] The adoption of the degraded standards of the old system is to ensure that a ceiling has been placed upon the development of color television. To adopt the higher standards of the newer system is to leave full scope for future development, and the attainment of far higher ultimate performance than is possible with the old.

In spite of these obvious facts the Commission's Report judges the ten year old incompatible system by far more lenient standards than those which it applies to the new high-definition compatible system which has only just begun to realize its potentialities. The Commission hopes that the recognized defects of the old system may be cured; it doubts that the alleged defects of the new system can be overcome.

B. Progress Cannot Be Served By Outlawing the New in Favor of the Old.

The Commission would outlaw the RCA system for all time because it was dissatisfied with what it saw at four demonstrations, the last of which was in April—only eight months after the new system was announced. Detailed technical expositions of the RCA color television system are contained in the record. But the Commission has apparently based its conclusion that the RCA system should be outlawed upon the basis of what it saw on the face of the receivers demonstrated, without understanding the

principles of the system involved in these demonstrations. In fact, the Report of the Commission prefaces its description of the RCA system with the statement that the Commission has found it difficult to describe the RCA system because "it involves new and complex techniques, many [fol. 305] of which were never clearly expounded during the hearing." Instead of satisfying itself as to the merits of the RCA system through understanding the alleged "new and complex techniques" involved, the Commission sought to judge the RCA system on the basis of the performance of laboratory apparatus.

Thus we find the Commission stating:

(a) ". . . at all of the demonstrations . . . there was *evidence of* faulty registration."*

(b) "At all of the *demonstrations* . . . RCA *had difficulty* producing a color picture with adequate color fidelity."

(c) "Picture texture was . . . marred at all of the *demonstrations* . . . by the visibility of dot structure at distances at which the lines *begin* to be unresolved."

(d) ". . . at that *demonstration* [of RCA direct-view tri-color tube receivers] there was *evidence of* faulty registration."

(e) ". . . as *demonstrated*, the tube developed insufficient illumination, it had an inadequate number of dots and it had a serious moire pattern in it."

These are very ingeniously phrased statements. They convey impressions which the words do not literally say. For example, it is not said that the RCA system has faulty registration, but that, at the demonstrations, there was "*evidence*" to that effect. Nor that the RCA system is incapable of color fidelity, but that, at the demonstrations, RCA "had difficulty" producing adequate color fidelity. [fol. 306] Even with respect to the recently developed RCA direct-view tri-color tube, which was demonstrated on April 6 with a highlight brightness of 7 footlamberts, the Commission has said there is "some doubt" whether the RCA system will permit "much higher brightnesses" for such a tube. There is no more basis for this statement than

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* Here and throughout the Comments emphasis has been supplied.

for the others.* RCA has already developed brightness many times that displayed on April 6.

The very same apparatus which the Commission saw was also viewed by a group of distinguished experts—the Committee headed by Dr. Edward U. Condon, Director of the National Bureau of Standards. They saw that apparatus for what it was intended to be—the demonstration of electronic principles. It is clear from their report† and their determination that the RCA system is entitled to 11 awards as the technically "superior system" against 8 for the system proposed by CBS that the Condon Committee did not confuse the distinction between laboratory apparatus and the principles of the system.

The error of the Commission's approach in judging the system which it describes as involving "new and complex techniques" by what it could see on the face of the receivers without adequate regard to the principles which were demonstrated by those receivers can be shown by an example.

We may take the invention of the airplane, and its first "demonstration" by the Wright brothers at Kitty Hawk. If we use the Commission's approach, this "demonstra- [fol. 307] tion" showed that the airplane could *not* be used as a means of passenger transportation, since the plane carried only the pilot. This is the static theory—to confine the significance of the "demonstration" to what was shown that day.

The dynamic approach would take that demonstration for what it was—the demonstration that an airplane *can be* a practical means of transportation. It would recognize that the statistics of that day in 1903 had only historical significance. It is true that only one person was carried by the plane. The weight which the Wrights got into the air

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* Some other respects in which the Commission's Report is in error are set forth in Annex B.

† *The Present Status of Color Television*, Report of the Advisory Committee on Color Television to the Committee on Interstate and Foreign Commerce—United States Senate, Senate Document No. 197, 81st Cong., 2d Sess. A copy of this Report is included in these Comments as Annex C, and examples of conflict between this Report and the Commission's Report are set forth in Annex A.

was but 750 pounds. Their maximum speed was only 30 m.p.h. The longest flight duration but 59 seconds. And, to say the least, their techniques were "new and complex".

But who remembers these statistical footnotes today? What is important and what the world does remember is that the Wrights had demonstrated a principle. The dynamics of the aircraft industry could and did translate these statistics into the airplane of today.

Applying the Commission's approach to the RCA system to the Wright brothers' demonstration at Kitty Hawk, the Commission would state:

> ". . . as demonstrated, the plane developed insufficient speed (30 m.p.h.), it had an inadequate carrying capacity (750 lbs.), and it had a serious limitation on duration of flight (59 seconds)."

It would follow that the airplane should never be approved as a means for public transportation.

Whether or not the Commission feels the RCA system is made "complex" by the introduction of new techniques, it is startling to find this asserted as a point *against* that [fol. 308] system. In this connection an observation by the distinguished scientist and President of Harvard University—James B. Conant—is of interest;

> "Tremendous spurts in the progress of the various sciences are almost always connected with the development of a *new technique* or the sudden emergence of a new concept."*

The RCA all-electronic, compatible, high fidelity color television system with its tri-color tube has been hailed by the scientific world as a major development in electronics. But it is this system that the Commission proposes to outlaw on the basis of four demonstrations simply because it is new, and the Commission says it is difficult for it to understand.

A salient example of the Commission's failure to understand the RCA system is the statement that in the RCA system "color control is exceedingly difficult to maintain." In this connection it refers to a tolerance of 1/11,000,000 of

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* Conant, *On Understanding Science* (1947) pp. 73-74.

a second. Of these statements, the first is wrong and the other misleading.

The ordinary black and white television receiver provides an accuracy in its synchronization process which is of the same order. If the synchronized horizontal scanning wave in such a receiver were to be shifted in time by 1/7,000,000 of a second in successive frames, details of the picture would be mislocated by approximately the width of a normal picture element, thereby losing half the picture resolution. Since most receivers suffer no appreciable loss of resolution, even in the presence of a noisy signal, the accuracy provided is far better than 1/11,000,000 second.

[fol. 309] For black and white television receivers the required accuracy is obtained through the use of automatic frequency control circuits. These same circuits can be effective in maintaining the needed accuracy for color television. The receiver circuit functioning is synchronized by the "burst" precisely at the start of each scanning line. Consequently the color control circuits are "on their own" for only 1/15,750 second, or the time of one scanning line.*

Tolerances of this order are encountered in many types of electronic equipment, such as radar and shoran upon the operation of which the safety and lives of men depend.

C. The Performance Capabilities of the RCA System Have Not Been Recognized By the Commission

The Commission's approach to the RCA system—its doubts with respect to that system—and its preference for the ten-year old CBS system give no effect to the dynamic nature of the electronic industry or to the potentialities of the RCA system. The capacity of the RCA system for spectacular and rapid simplification in equipment design, while improving equipment performance, is nowhere referred to.

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* Mr. Donald Fink, the editor of *Electronics* magazine, a member of the Condon Committee, and a disinterested expert in this field, stated at the hearing that

> ". . . the stability with which synchronizing circuits of black and white receivers have turned out to work in the home is ample evidence that the synchronizing of dot interlace can be accomplished in the same manner and with about the same degree of success."

Last October RCA demonstrated laboratory models of color sets of the 3-kinescope type. They had more than 100 tubes. Within six months, when the RCA direct-view [fol. 310] tri-color tube receiver was shown, this number had been cut to 46 in one set and 37 in another.

In October Dr. Goldmark of CBS took the position that "nothing" could improve the RCA system. He later admitted, on the record, that the RCA picture had improved "a thousand percent".

CBS' own expert, Dr. Judd, of the National Bureau of Standards, stated that he had seen a demonstration of RCA color which

> ". . . was the equal of any of the CBS shows on color fidelity".

One of the Commissioners commented that

> ". . . we have seen that [the RCA system], and it produced beautiful color".

Another Commissioner remarked, in respect to the RCA system, that

> ". . . your picture is greatly improved since your first showing".

In spite of these observations with respect to color fidelity, the Report of the Commission says that ". . . there appears to be no reasonable prospect that these difficulties in the RCA system can be overcome . . ." and that "It is difficult to see how these defects can be eliminated". Again ". . . it is difficult to see how color control can be simplified . . .".

For RCA's part it has never for a moment assumed it would not be "difficult" to deal with problems in this field of research.* But RCA has never shared the Commission's [fol. 311] defeatist attitude in respect to them. On the contrary RCA has felt and expressed the same confidence that its competitors in research expressed on the record.

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* President Conant again is in point. In the book refered to he said:

> ". . . new concepts only develop after an arduous period of experimentation." (p. 36)

Referring, for example, to the problems of registration, Dr. DuMont said

> ". . . there are ways and means to overcome that".

Dr. Goldsmith, the Director of Research of Allen B. DuMont Laboratories, said

> ". . . the registration problem is just an equipment limitation at the present time, it is not a fundamental limitation. It can be overcome completely".

Dr. Baker, the head of the Electronics Division of General Electric, testified

> "I feel confident that it [registration at the camera] can be licked".

Mr. Donald Fink, the editor of *Electronics* magazine and a member of the Condon Committee, said that registration

> ". . . is a problem which . . . can be approached . . . on a strictly engineering basis, to improve it in the same way as we have improved everything else in television".

All but unanimously the industry has recommended the adoption of an all-electronic, compatible, high definition color television system—such as the RCA system. Neither the industry nor the Condon Committee was daunted by the doubts which appear in the Commission's Report. Further, the statements set forth in the RCA Progress Report [fol. 312] of July 31* confirm the testimony of industry experts and the statements in the Condon Report as to the potentialities of the RCA system.

We believe that in a rule-making proceeding of the importance of this one, it is the duty of the Commission, before making findings at odds with those of a group of scientists of the stature of the Condon Committee, to keep the record open and to inform itself as to the basis for the findings of that Committee.

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*A copy of this Report is included in these Comments as Annex D. Examples of conflict between the technical testimony, confirmed by the RCA Progress Report, and the Commission's Report are set forth in Annex A.

We believe that, in the circumstances, the Commission had the same obligation with respect to the RCA Progress Report. That report was given to the Commission a month before its decision. If the testimony of the electronics experts to whom we have referred had been accepted, there would of course have been no need to consider a report which said that improvements which had been promised during the hearing had actually been accomplished. But a decision was drafted which rejected that testimony and outlawed a system on the basis of alleged defects which the Progress Report said had already been eliminated. This, we submit, was to turn its back on evidence when the Commission had an obligation to look.

D. The Commission's Report Does Not Encourage the Larger and More Effective Use of Radio in the Public Interest

Section 303(g) of the Communications Act of 1934 as amended provides that the Commission shall "encourage the larger and more effective use of radio in the public interest". As one of the Commissioners has expressed it, the Commission

> [fol. 313] ". . . has the affirmative, statutory duty to look to the future. Section 303(g) of the Communications Act provides that the Commission shall '. . . encourage the larger and *more effective* use of radio in the public interest'. In fulfilling this statutory mandate we cannot simply be content *with what is here today*, but we must look to see *what may be tomosrow, what new developments* radio may bring . . ." *

The task before the Commission is the adoption of standards that should last for decades. The Commission is passing on systems; not merely on the apparatus of today. The statutory obligation is clear. The Commission has the duty to adopt a long-range concept of what is in the interest of the public. The outlawing of the RCA system in favor of the CBS system cannot be squared with the Commission's statutory obligation.

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* From the speech by Commissioner Hennock on September 15, 1950.

As Mr. Fink pointed out, the fixing of standards has an ominous negative aspect. Standards place a ceiling on progress. That ceiling must therefore be a high one. In its decision of 1947 relating to color standards the Commission stated that

> "Before approving proposed standards, the *Commission must be satisfied* not only that the system proposed will work but also *that the system is as good as can be expected within any reasonable time in the foreseeable future.*"

Instead of adhering to a long-range view, the Commission's present Report is based on short-range considerations. It looks only to "what is here today". It does not say we must have an "excellent" color system by today's standards, in order that that shall be at least "good" by tomorrow's. It is ready to settle for an "adequate" system of today.

[fol. 314] In 1940 and 1941 the Commission held out strongly for higher definition and *the fullest utilization of the bandwidth.* In adopting the present monochrome system in 1941 it pointed out that

> ". . . 525 lines provide for *greater detail* in the pictures transmitted than the 441 lines advocated a year ago. They . . . more fully exploit the possibilities of the frequency bands allocated for television".

But now the Commission is willing to settle for 405 lines. It characterizes these as giving "adequate apparent definition".* The Commission has admitted that the CBS system

> ". . . has *less* geometric resolution than the present monochrome system".

It purports to justify this degradation in color standards by the statement that

> ". . . the addition of color more than outweighs the loss in geometric resolution so far as *apparent* definition is concerned".

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* It should be noted that the language is doubly hedged. It is not even "adequate definition". It is only "adequate *apparent*" definition.

If the Commission is to meet its statutory obligation to promote "the *more* effective use of radio", we believe it must provide for a system of color television in which the element of color is *a plus factor,* when compared with the monochrome system, and not a factor used to make up for degradation of resolution which the monochrome system does not have. The Condon Committee found that this could be done. Their approach was that in adopting a color system the public could have color as an added factor and not a balancing factor.

[fol. 315] There is no reference whatsoever in the Commission's decision to the desirability of a system which most fully exploits the possibilities of the frequency bands. The Condon Committee does refer to this and says that it is one of the outstanding points of superiority of the RCA system.

In dealing with brightness the Commission again is willing to settle for what it claims is "adequate" brightness.

In connection with the reception of color transmissions in monochrome, the Commission takes what is perhaps its most extreme position in respect of standards. The defeatist attitude of the Commission, its disregard of the public service, is epitomized in its discussion of this point, where it states:

> "There appears to be no alternative to some *degradation* in the quality of the black and white picture from color transmissions . . ."

If ever the public was entitled to conclude that a system had been damned with faint praise, that conclusion is justified with respect to the CBS system on the face of the Commission's Report.

E. The Commission's Present Conditions for Consideration of Color Television Systems Are Inadequate and Unfair.

In the Commission's Notice of Hearing for this case, there were stated two requirements which any color television system proposed had to meet. These were (1) that the system should operate in six megacycles; and (2) that

[fol. 316] existing television receivers should be able to receive the new transmissions

> ". . . simply by making relatively minor modifications in such existing receivers."

RCA met both requirements in the most dramatic and satisfactory way. With the RCA all-electronic high definition compatible system no change at all is required in existing receivers and all programs may be received on such receivers without any degradation of picture quality.

In the case of the CBS system on the other hand, modifications of existing receivers are necessary. Even then the existing receivers can receive only a degraded picture from the color transmission.

CBS urged that these modifications of existing receivers were minor. The Commission has now stated that the manufacture of continuously adjustable bracket standard receivers is the way to provide for the reception of CBS color on future black and white sets. This change in the Commission's determination as to the way in which the CBS color transmissions should be received on black and white sets requires major modifications in black and white sets. As a result CBS does not meet one of the basic conditions on which the entire hearing was held. The Commission's Report disposes of this difficulty in the CBS system by leaving this point out of its present list of conditions for the consideration of a color television system. Thus the case was tried on one basis and decided on another.

Indeed the new list of conditions for the consideration of color television systems is notable for its omissions rather than for what is included. Neither compatibility, high defi-[fol. 317] nition, nor absence of limitations on picture size are specified as conditions, although it is obvious that these three factors are of the greatest importance to the Commission, the industry and the public.

It is conceded by all parties on the record that compatibility is of the utmost importance. It is compatibility that makes it economically practical for the broadcaster and the sponsor to broadcast

in *color*
their choice programs
in choice time

as soon as standards for a compatible system are approved.

With a compatible system the broadcaster does not have to wait for color receivers to appear in quantity. Nor does he have to confine color broadcasts to fringe time. Thus the most important single factor in this hearing, from the standpoint of insuring an early development of color television, is compatibility.

The Commission makes a bow to the economics of broadcasting by specifying that cost of station equipment must not be so high as unduly to restrict the class of persons who can afford to operate a television station. However, in the economics of broadcasting the cost of station equipment is a very minor matter in comparison with the matter of circulation revenue, as CBS itself has conceded on the record. The latter could of course be preserved by the adoption of the RCA compatible system. Thus the Commission's conditions include a factor of minor importance to the broadcaster, of no importance to the public or to the owners of television receivers, while they omit compatibility, a factor of major importance to the [fol. 318] broadcaster and of major importance to the public and to the owners of television receivers.

The Commission also makes a bow to the importance of high definition and absence of limitation on picture size. This is not done in the specified conditions for consideration of a color television system but by the interest displayed in dot interlace and the use of the tri-color tube in the CBS system.

None of these three essential factors for any color television system, however, is specified by the Commission as having any bearing at all upon the ultimate adoption of color television standards.

To omit these factors in listing the conditions essential to a color television system is to depart from the Commission's obligation to serve the public interest. While the omission of these factors would enable the Commission to adopt an inferior color television system, the omission clearly does not aid the Commission in performing its statutory obligations.

The answer to the question whether one would prefer to own a horse and buggy or an automobile today seems obvious. But if you exclude the factors of speed, endur-

ance and comfort, some might feel that the answer would be entirely different.

The Proposed Bracket Standards for Black and White Television Are Unnecessary, Costly and Contrary to the Public Interest

The Commission's Notice proposes changing the present 525 line 60 field black and white standards which have been in existence for nine years. The Commission's Notice [fol. 319] does not propose any specific change in lines or fields. The Notice would instead substitute for the existing standards a line frequency variable from 15,000 to 32,000 per second and a field frequency ranging from 50 to 150 per second.

The Commission's Report, upon which the Notice is based, indicates that the Commission's proposal to adopt these variable standards for black and white television rests upon two considerations:

(a) The Commission's apparent desire to depart from the established practice of fixing a specific number of lines and fields on the basis of a hearing directed to those specific values; and

(b) The Commission's desire to be in a position to adopt the incompatible CBS color system at some later date without regard to the incompatibility, degraded resolution and other defects of that system.

In so far as the Commission's proposal to change the black and white standards rests upon its desire to adopt the CBS color system, the proposal is without foundation. As has been set forth above, the Commission's rejection of the RCA color system is entirely unwarranted since the only basis upon which the Commission's report would adopt the CBS system is the absence of a practical compatible system. But there *is* an entirely practical compatible system—the RCA system.

In addition, the Commission's Report recognizes that more must be done with the CBS system before it should be adopted. The only *color* reason for bracket black and white standards is to obtain the time believed necessary to improve the CBS system. This time is to be obtained [fol. 320] by imposing the unnecessary cost of bracket standard receivers upon the public for an indefinite period.

This burden on the public is unjustifiable particularly in view of the fact that the RCA system has greater potentialities for improvement—and superior ultimate performance—than the CBS system. Furthermore, the potentialities of the RCA system can be realized within the fundamentals of the present television standards,* thus making bracket standards entirely unnecessary and imposing no additional costs on the public.

The reasons set forth below against the adoption of the bracket standards and against the manufacture of bracket standard receivers, from the standpoint of the black and white service, also tend to establish even more firmly that the proposed change is not desirable in order to provide for color service.

A. The Present Standards Should Not Be Abolished, Without a Hearing, In Favor of Bracket Standards.

The present standards for black and white television (15,750 lines per second and 60 fields per second) were adopted in 1941 after extensive public hearings and equally extensive consultation with various industry committees. No change in such standards, and particularly no change of the scope now proposed by the Commission (line frequency variable from 15,000 to 32,000 per second and field frequency ranging from 50 to 150 per second), should be adopted without adequate hearings and industry study.

[fol. 321] The Commission's Notice seeks the adoption, on 28 days' notice and without a hearing, of standards which include any and all combinations of lines and fields within the very widely specified limits of the proposed bracket standards. In 1941, the precise combination of 525 lines and 60 fields was carefully arrived at by the Commission after bitterly contested hearings arising from conflicting engineering views as to what particular combination would best serve the public interest, convenience and necessity.

The procedure provided by the Commission since 1941 for all changes in television standards is set forth in the

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* The standards which RCA has proposed for its color system include all those currently in effect for black and white television. The additional standards which must be added for color have no effect upon the operation of black and white receivers.

Commission's Rules (Section 2, Part B of the Commission's Standards of Good Engineering Practice Concerning Television Broadcast Stations). These rules provide that the Commission will not consider a proposed change or modification of transmission standards adopted for television except upon petition setting forth (a) the exact character of the change proposed, (b) the effect of the change upon all other transmission standards for television broadcast stations, (c) the experimentation and field tests that have been made to show that the proposed change accomplishes an improvement and is technically feasible, (d) the effect of the proposed change upon operation and obsolescence of receivers, (e) the change in equipment required in existing television broadcast stations for incorporating the proposed change, and (f) the facts and reasons upon which the proposed change would be in the public interest, convenience, and necessity.

The Commission's Notice does not set forth the information required by the Commission's rules, and such information [fol. 322] is not made available by the record in the hearings in the color phase of the above entitled proceedings. There is no evidence in the record regarding any of the six items specified in the Commission's rules with respect to changes in standards, for no proposal was made in these proceedings for any change in the black and white standards until the issuance of the Notice.

The Commission has indicated in its Report that the only advantage of bracket standards to the black and white service itself is the bare possibility of working out sometime in the indefinite future a combination of lines and fields, which, in utilizing horizontal interlace and long persistence phosphors, might make more effective use of those developments than would the present combination of 525 lines 60 fields.

The possibility that the adoption of bracket monochrome standards now would lead in the future to a better black and white picture is only a speculation. But it is certain that the adoption of such standards now and the manufacture of bracket standard receivers in accordance with the Commission's specifications would immediately result in a substantial increase in the cost to the public of television receivers.

There is no evidence in the hearings of the color phase of the above entitled proceedings with respect to bracket standard receivers of the kind now called for by the Commission. The evidence in those hearings related simply to an internal or external adapter which, when added to then current models of black and white receivers, would enable them to receive either 15,750 lines 60 fields or 29,160 lines 144 fields per second. Engineering data or cost esti-[fol. 323] mates relating to such internal or external adapters are not relevant to the bracket standard receiver which must be capable of operating at any combination of lines and fields within the wide range prescribed by the Commission.

B. The Manufacture of Receivers Capable of Operating Under the Proposed Black and White Standards Would Be Contrary to the Public Interest

The Commission has asked manufacturers of television receivers whether they will design and manufacture television receivers capable of operating within continuously variable standards, having a switch so as to be able to select one of two specified sets of standards, and capable of producing black and white pictures of equivalent size, geometric linearity and brightness on each of two specified sets of standards. In addition, the Commission has asked the manufacturers whether they will commit themselves to the manufacture of such receivers not later than 30 days after the publication of the bracket standards in the Federal Register; this commitment to cover each and every television receiver made by such manufacturer after that date.

In the time, and with the information, available since the issuance of the Commission's Notice, RCA has not been able to complete designs of the receivers specified in the Commission's Notice. Because these designs have not been reduced to practical apparatus and tested, they are necessarily subject to change as experience may require. On the basis of the designs developed so far, it is apparent that the receivers called for by the Commission's Notice will require a major redesign of existing receivers, rather [fol. 324] than merely the addition of circuits and components. For example, in order to meet the proposed standards, the horizontal synchronization and deflection

system must be revised. In addition, the vertical synchronization and deflection system and the power supply system must also be revised.

(i) *Horizontal Synchronization and Deflection System*

The Commission's proposed bracket standards require that the horizontal line frequency be variable within the bracket 15,000 to 32,000 cycles per second. When television andards were first being considered, proposals were made for flexible television standards which would require a variable line frequency. At that time the synchronizing circuits employed were of the "triggered" type and capable of a relatively wide range of frequency adjustment. The "triggered" type of horizontal synchronizing circuit has since become obsolete because of its susceptibility to interference.

Modern receivers employ the "automatic frequency control" type of horizontal synchronizing circuit which provides a very high degree of noise immunity. This noise immunity is achieved through the use of circuits with inherent frequency stability; thus the horizontal synchronizing circuits now employed are adjustable over a very limited frequency range.

Therefore, in order to meet a frequency range such as proposed in the Commission's Notice, it is necessary to change the circuit constants in steps, each of which will cover only a limited range of frequencies. Expensive switching arrangements are thus necessary to provide the [fol. 325] horizontal frequency range from 15,000 to 32,000 cycles per second.

The proposed CBS standards of 144 fields and a horizontal frequency of 29,160 cycles per second call for a horizontal blanking time of between 16 and 18 percent. In order to meet a 16 to 18 percent blanking time for the horizontal frequencies in the proposed bracket standards, a retrace time in the receiver of approximately 4 microseconds will be necessary. This retrace time is approximately one-half that now employed in present monochrome receivers. Meeting the 4 microsecond requirement necessitates major changes in the horizontal deflection circuits.

Among the changes required in present television receivers, in addition to provision for manual or automatic

switching between two sets of standards in order to meet the requirements of the proposed bracket standards are:

(a) A higher powered and more expensive output tube for horizontal deflection must be substituted for the tube presently used.

(b) A more expensive horizontal deflection transformer and circuit must be employed in the receiver. This transformer must have approximately one-half the inductance and one-half the distributed capacity of the present transformer and be capable of handling additional power.

(c) A damper tube circuit which provides the desired picture linearity must have double the power-handling capabilities. An additional damper tube will be necessary to meet this requirement.

[fol. 326] (d) The deflection yoke must be redesigned to provide greater protection against voltage breakdown, since higher potentials are produced.

(e) An additional filament transformer is required to supply the heaters of the two damper tubes.

(f) Additional items are necessary for the horizontal circuit as follows:

2 linearity coils
2 width potentiometers
3 linearity capacitors
1 sine wave transformer with taps
2 sync separator resistors
8 miscellaneous resistors

(ii) *Vertical Synchronization and Deflection System*

Since the vertical synchronization circuits are essentially of the "triggered" type, the modifications to the vertical circuits to cover the range from 50 fields to 150 fields are not as great as the changes which are required in the horizontal deflection circuits. The changes required involve provision for manual or automatic switching between two sets of standards and additional components as follows:

2 vertical hold potentiometers
1 height potentiometer
1 vertical linearity potentiometer
8 miscellaneous resistors.

[fol. 327] (iii) *Power Supply System*

The reductions in the price of television receivers which have been achieved, have in large part resulted from the more efficient use of materials and components. For example, the power supply system used in these receivers is designed to handle only the requirements of a specific receiver. In order to supply the additional power required by the changed horizontal and vertical deflection systems, a larger power supply system must be employed. The following power supply changes are necessary in RCA's present receivers in order to meet bracket standards:

(a) The power transformer must be increased in power-handling capabilities to provide the increased power required by the horizontal and vertical deflection circuits.

(b) An additional rectifier tube is necessary to handle the required current.

(c) Since the bracket standards involve frame frequencies which are not synchronous with the power supply frequency, increased magnetic shielding will be required. This shielding includes a magnetic shield box for the power transformer and special magnetic shields for the cathode ray tube.

In addition to the components set forth above, various switches are also required in order to meet the Commission's specifications. These switches will permit selection between two sets of standards and will vary in number and complexity depending on whether they are automatic or manual.

[fol. 328] Automatic switching for the bracket standards would require the following additional components in an RCA receiver:

1 tube
1 20-contact relay for horizontal deflection circuit
1 6-contact relay for vertical deflection circuit
1 tuned circuit for the horizontal deflection frequency
Miscellaneous components, including resistors and capacitors

RCA believes that, even assuming bracket standard receivers could ever be commercially acceptable, they would

have to include automatic switching. RCA's experience shows that the viewing public will be unwilling to leave their seats and operate a manual switch every time a broadcaster changes from one type of transmission to another.

(iv) *Unjustifiable Additional Cost to the Public*

For a medium priced set the additional cost to the consumer which would be involved in the manufacture of the proposed receivers is estimated at approximately $61 for the automatic type of continuously adjustable internally adapted bracket standard receiver. If RCA should build and offer a receiver which would be in all respects the same except that the operation would be manual instead of automatic the additional cost to the consumer is estimated at approximately $50.

Current industry production is at the rate of about 6,500,000 sets a year. On the basis of the figure for the automatic type receiver, the increased cost to the public [fol. 329] which would result from the Commission's proposal would be approximately $400,000,000 per year. For this tax on the public the purchasers of these receivers may never get anything. If they do get anything it will be only a degraded black and white picture. Even for $400,000,000 a year it will not be color.

Even if the Commission at some future time should find (a) that horizontal interlace should be incorporated in the black and white standards, (b) that long persistence phosphors have the performance now claimed for them and that those characteristics should be recognized in those standards, and (c) that a change from 525 lines 60 fields to some other combination of lines and fields is desirable, *those who had bought the bracket standard receivers and paid the additional sums required would not receive an improved picture when the change was made.* Their receivers would have neither the horizontal interlace circuits nor the type of kinescope required to realize the benefits of such changes in the transmission standards. In order to realize those benefits they would have to add the interlace circuits and a kinescope incorporating the long persistence phosphors.

In addition, the foregoing has been premised on the assumption that, in the future, the Commission may change black and white television from 525 lines 60 fields to a different combination of lines and fields. But it may well

be that future experimentation with the effects of horizontal interlace and long persistence phosphors on black and white television will prove that no substantial improvement in picture quality would result from their use on a different combination from 525 lines 60 fields.

[fol. 330] C. Receivers Capable of Operating Under the Proposed Black and White Standards Cannot Be Produced Within the Time Schedule Specified by the Commission.

The Commission has asked manufacturers of television receivers whether they will agree to convert their entire production from the present 525 line 60 field black and white receivers to the bracket standard receivers not later than thirty days after the publication in the Federal Register by the Commission of a final order adopting bracket standards. The Commission's Report contemplates that no hearing will be held with respect to the adoption of bracket black and white standards and that, therefore, if such standards are adopted, they will be adopted early in October. This means that the Commission is asking the manufacturers to agree not to build any receivers other than bracket standard receivers commencing in the early of part of November.

Even assuming that satisfactory production designs of bracket standard receivers arrived at after sufficient design testing were at hand, it would be impossible to get into commercial production of these receivers within the time required by the Commission or any approximation of that time. The preliminary engineering studies of the changes which would have to be made in RCA present production models to comply with the Commission's specifications show that such receivers would have to be completely redesigned, and that bracket standard receivers could not begin to come off the production line before the second quarter of 1951.

In addition there has been no design testing of these bracket standard receivers. RCA feels it cannot gamble [fol. 331] with the public's money and the good will of this company by building and selling receivers incorporating such changes in fundamental design without thorough tests. In view of the nature of the changes required by the Commission's specifications for bracket standard receivers, the

time necessary for the sort of testing that is required before production designs of commercial models can be developed is also considerably longer than that allowed by the Notice.

D. The Manufacture of Bracket Standard Receivers Would Have an Inflationary Effect and Lower the Already Critically Short Supply of Television Receiver Components.

The record in this hearing closed on May 26, 1950, approximately a month before the United States became involved in a war in Korea and before its expanded defense program was commenced. The necessity in the public interest of reducing and resulting strains on the country's economy has since been set forth in the Defense Production Act of 1950.

Among the objectives of this statute is the promotion of the national defense "by preventing undue strains and dislocations upon . . . prices."

The Commission's proposal for the manufacture of bracket standard receivers is, we submit, contrary to this statutory policy. The manufacture of such receivers would have an inflationary effect in that it would increase substantially the cost to the public of every television receiver bought for the indefinite future. It would mean the unnecessary use of critical materials and an unnecessary increase in the price of television receivers.

The action of the Commission would bring about these results on the false assumption implicit in its Report that [fol. 332] a satisfactory compatible system does not exist now and cannot be produced even in the foreseeable future.

Since the start of the Korean conflict, industrial activity has increased substantially, resulting in increased shortages of certain materials and making the procurement of certain television components much more difficult. The additional components which would be needed for bracket standard receivers use iron, steel, copper, nickel, tin and tungsten, all of which have been found by the National Production Authority in its first regulation issued on September 18, 1950 to be in critically short supply.

The television industry already faces difficult and acute problems arising from severe shortages of tubes and components. The manufacture of bracket standard receivers would intensify the difficulties which already exist as a

result of these shortages and would operate to curtail substantially the number of receivers available to the public.

If this were necessary the country would of course have to be subjected to the increased economic strain that it involves. But it is not necessary. This inflationary effect can be avoided and these critical materials saved for the nation's paramount needs by the adoption of a compatible system.

Conclusion

The Commission's action is unique. Never before has an administrative body of the United States undertaken to coerce the freedom of choice of American manufacturers in what they may build and sell under threat that if they do not obey, drastic consequences to the public will follow. [fol. 333] We urge withdrawal from this unprecedented position, not only in respect of its future implications to American business but as well in the interest of 40,000,000 people who are now enjoying television.

Before a final decision is rendered which would degrade the present black and white television service and impose upon the public a scientifically inferior color system, we urge recourse to the opinion of the American people. They are vitally interested. Their voice should be heard.

Radio Corporation of America, (s) C. B. Jolliffe, Executive Vice President in Charge of RCA Laboratories Division.

September 28, 1950.

[fol. 334]

Annex A

Commission's Report Conflicts With Condon Committee and RCA Progress Reports

The Commission failed to consider matters of great significance which have been fully available to it since the close of the hearings on May 26, 1950. The Commission has closed its eyes to developments taking place after the close of the record, and has written its report as if time had stood still since May 26.

The Commission's failure adequately to inform itself has resulted in fundamental conflict between the Commission's Report and the findings of the Condon Committee

with respect to the technical characteristics of the RCA and CBS color systems. Some of the examples are:

Condon Committee Report	FCC Report
A. "The effectiveness of channel utilization of the RCA color system is the highest of all the systems discussed in this report". (p. 36)	In spite of the Commission's statutory obligation to promote "the more effective" use of the radio spectrum, the Commission's report does not mention the relative effectiveness of channel utilization by the RCA and CBS systems.
B. RCA is the only system which can make use of the mixed highs principle and its use has been conclusively proved to result in a saving of band width. (pp. 18, 38)	The Commission's Report only states that it is "claimed" that the use of mixed highs by the RCA system has saved band width. (Pars. 50, 51) No reference is made to the fact that only the RCA system is able to make use of mixed highs.
C. By the use of dot interlace, an integral part of the RCA system, it is possible to achieve a picture with almost twice as much resolution as is possible on the same band width without dot interlace. (pp. 8-9)	The Commission has found only that RCA "endeavors" to save band space by the process of dot interlace. (Par. 51)
[fol. 335]	
D. Because of the difference between the field repetition rate of the CBS system and the RCA system, the RCA image can be about nine times as bright as the CBS image for equal visibility of large area flicker. (pp. 26-27, 34)	This superiority of the RCA system over the CBS system in freedom from flicker is not mentioned.
E. ". . . no adverse effects are noted from the use of mixed highs." (p. 18)	The so-called "difficulty" which the Commission has stated is encountered by the RCA system in maintaining adequate contrast in small areas is said by the Commission to be due, among other things, to the use of mixed highs. (Par. 76)

Condon Committee Report	FCC Report
F. Fidelity of color reproduction depends upon what primaries are used and there is "no basic difference in the color fidelity of the three color systems". (p. 28)	This fundamental fact is not mentioned in the Commission's Report.
G. "No adverse effect" upon color detail results from the use by RCA of dot interlacing and mixed highs, and in particular the use of mixed highs does not result in "appreciable degradation of the color or tonal values of the image." (pp. 18, 33)	The Commission asserted that because of RCA's use of mixed highs and the way it incorporates horizontal dot interlace, color detail in small areas of the picture cannot be faithfully produced. (Par. 87)
H. "The RCA color image has an over-all resolution approximately equal to that of the black-and-white system". (p. 35)	The Commission found, with respect to the RCA system, that its resolution "even in theory is not equal to that of the present [black and white] system *for all types of scenes*."* (Par. 91)
I. ". . . the presence of the mixed highs component in the [RCA] color transmission assures high resolution in the black-and-white rendition". (p. 34)	The Commission found that although no change in existing receivers is required in order to enable them to receive black and white pictures from RCA color transmissions, "the picture so received is somewhat inferior to present black and white pictures". (Par. 107)

[fol. 336]

Condon Committee Report	FCC Report
J. "The black-and-white rendition of the RCA color transmission has higher resolution and better flicker-brightness performance" than does the black and white rendition of the CBS color system. (p. 34)	The Commission has implied that the quality of the black and white rendition from the CBS color system on an adapted receiver is as good as the black and white rendition from RCA color transmissions on a standard receiver. (Par. 143)

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* Note how this is hedged. The whole statement is limited by the words "for all types of scenes."

The result of the Commission's failure adequately to inform itself is also shown by the statements in the Commission's Report which are wholly inconsistent with the testimony of informed witnesses as to what developments were possible with the RCA system and associated apparatus, and with the statements as to what had already been done in RCA's Progress Report of July 31, 1950. This Progress Report was sent to the Commission a month before the Commission issued its First Report. The following are illustrative:

Evidence in Record	Statement of Accomplished Fact in RCA Progress Report	Commission Statement in First Report
(A) Tri-color tube demonstration on April 6 showed 7 footlamberts brightness. Testimony was that there is "no reason why we cannot have 20, 25, 30" footlamberts brightness or more. (Engstrom, 8158, 10882)	RCA color system receivers utilizing tri-color tubes now produce pictures with highlight brightness of more than 20 footlamberts; and before long brightnesses of 40 to 50 footlamberts will be achieved. (pp. 1-2)	"At none of the demonstrations on the record did any of the RCA color receivers produce sufficient illumination for ordinary home use" and "there is some doubt" whether the RCA system will permit much higher brightness [than 7 footlamberts] on the tri-color tube. (Par. 76)
[fol. 337]		
(B) Dot structure and moire pattern can be eliminated from the RCA picture without any accompanying undesirable effects. (Brown, 10748-54; Engstrom, 8138)	Dot structure and moire pattern have been substantially eliminated due to use of improved receiver circuits and increased number of phosphor dots. (p. 1)	There was no demonstration by RCA of minimizing dot structure and "it appears to the Commission that if the dots are smoothed out, the consequences are likely to be a loss in resolution or contrast, or in both." The RCA tri-color tube "had a serious moire pattern in it". (Pars. 97, 116)
(C) The RCA tri-color tube demonstrated on	The resolution afforded by the tri-color tube has been	"As demonstrated [on April 6], the [RCA tri-color] tube

Evidence in Record	Statement of Accomplished Fact in RCA Progress Report	Commission Statement in First Report
April 6 had 351,000 phosphor dots which resulted in a reduction of resolution. The number of phosphor dots will be doubled. (Engstrom, 7842-43, 7918)	increased because of the increase in the number of phosphor dots from 351,000 to 600,000. (p. 1)	had an inadequate number of dots." (Par. 134)
(D) Receivers will be further simplified and color controls made more stable and less critical (Engstrom, 6094-95; Brown, 8545)	Receivers have now been developed incorporating new simplified and stable circuits. (p. 2)	The receiving equipment utilized by RCA is exceedingly complex and the Commission "is not satisfied that the [tri-color] tube solves the problem of complex receivers". Color controls are critical and not stable. (Pars. 115, 134)

[fol. 338]

(E) A corrective filter was used at the April 6 demonstration of the RCA tri-color tube because of the inadequacy of the red phosphor. This is a temporary condition. (Engstrom, 8153)	A red phosphor of proper chromaticity has been developed. (p. 1)	The RCA tri-color tube "suffers from the limitations as to color fidelity which are involved in the use of color phosphors rather than filters". (Par. 87)

[fol. 339]

Annex B

Additional Errors in Commission's First Report

There is set forth below a list of some of the other respects in which the Commission's First Report is in error. For the assistance of the Commission, the topical outline used in the Report is followed.

Description of Systems

The First Report of the Commission prefaces its description of the RCA system with the statement that the Commission has found it difficult to describe the RCA system because it involves new and complex techniques. In view of the errors of technical fact regarding the RCA system in the Commission's Report, it is clear that the Commission failed to understand the RCA system.

The statement that the RCA system involves new and complex techniques is misleading. As Dr. Engstrom of RCA testified at the hearing, the RCA system "is based upon several principles for which we have a background of experience. These include the principles of 'mixed-highs' resulting from our simultaneous color research, picture-dot interlacing resulting from our general television research, and sampling and time multiplexing in a restricted frequency band from our radio communications research. Each of these developments goes back one to several years. It is the combination of these which is unique." (2659)

In its description of the RCA system, the Commission found only that it "is claimed" that the use of mixed highs by the RCA system has saved band width. (Pars. 50, 51) [fol. 340] As the Condon Committee found on the basis of the Hazeltine demonstration, there has been "conclusive proof of the efficacy of the mixed-highs technique". (p. 38)

In its description of the RCA system, the Commission has found only that RCA "endeavors" to save band space by the process of dot interlace. (Par. 51) By use of dot interlace and mixed highs it is possible to obtain a picture with almost twice as much resolution as is possible in the same band width without dot interlace.

In describing the RCA system the Commission stated as of some significance that RCA "projection receivers were not exhibited again after the original [October 10, 1949] demonstration" (Par. 53) and in its evaluation of the RCA system the Commission stated that "projection receivers shown at the first demonstration were withdrawn by RCA and not resubmitted". (Par. 115) The statements of the Commission are incorrect. An RCA color projection receiver was again demonstrated at Laurel, Maryland on February 23, 1950.

Evaluation of Systems

In its discussion of the various specific system characteristics, the Commission's Report constantly shifts from apparatus to system considerations. The effect of this shifting is unjustifiably to the advantage of the CBS system. The asserted advantages of the CBS mechanical disc apparatus are found to be advantages of the CBS system; the shortcomings and limitations of such apparatus are not regarded as limitations upon the CBS system since they can be removed by using all-electronic apparatus. Yet [fol. 341] the Commission has failed to attribute to the theoretical all-electronic CBS system those defects which it attributes to all-electronic apparatus and holds against the all-electronic RCA system.

Flicker, Motion Continuity, and Allied Effects

The Commission has omitted the most important and fundamental technical fact with respect to flicker. Because of the difference between the field repetition rate of the CBS system and that of the RCA system, flicker is a more difficult problem for the CBS system. Moreover, the RCA image can be about *nine times as bright* as the CBS image for equal visibility of large area flicker.

The Commission's Report recognizes that if horizontal interlace were utilized in the CBS system to improve its geometric resolution, small area flicker would result. However, the FCC Report goes on to observe that since this is a flicker problem, "tubes with long persistence phosphors *should* minimize the problem." (Par. 67) For the RCA system, however, the Commission Report states only that "it is *possible* that this [small area flicker] effect may be overcome or minimized by the utilization of tubes with long persistence phosphors." (Par. 70) There is no distinction between the two systems in this respect.

The Commission has stated that if long persistence phosphors were successful in reducing small area flicker in the RCA system, the effect of such phosphors "on color fidelity and the portrayal of objects in motion would have to be carefully evaluated." (Par. 70) However, in its appraisal [fol. 342] of the CBS system, when the Commission relies upon the effect of long persistence phosphors to eliminate the CBS large area flicker problem and to reduce small area flicker in the dot interlace version of the CBS system,

there is no such *caveat* as to the effect of long persistence phosphors on color fidelity and the portrayal of objects in motion in the CBS system. There is no distinction between the two systems in this respect.

Brightness—Contrast

The Commission stated that "there is some doubt" as to whether much higher brightnesses than the 7 footlamberts achieved at the first demonstration of the RCA tri-color tube can be obtained when the tri-color tube is used on the RCA system. (Par. 76) As the Commission was informed on July 31, 1950 in the RCA Progress Report, RCA had already by that time achieved tubes with highlight brightnesses of more than 20 footlamberts.

Although the Commission has stated that the brightness of all RCA receivers demonstrated was inadequate (Par. 70), this statement is inconsistent with its request that RCA make available an RCA dichroic mirror receiver "similar to that . . . demonstrated" in order that the Commission could view a CTI demonstration "with relative high brightness and on a direct viewing device." A copy of the Commission's request is attached hereto as Annex E.

The Commission stated that the 20 to 30 footlamberts obtainable on CBS disc receivers was bright enough for use in the home. The Commission overlooked, however, the severe loss in brightness which would occur when existing black and white sets are converted to CBS color. If the [fol. 343] figure of 17 footlamberts highlight brightness for present black and white receivers set forth in footnote 18 of the Commission's Report is taken and in addition the Commission's illustrative figure of 90 percent for loss in light occasioned by the use of the filter disc is used, the result would be that converted receivers would have a highlight brightness of no more than 1.7 footlamberts.

Superposition of Color Images

The Commission has found that the "CBS system is not troubled by other than minor registration problems . . .." (Par. 81) Any advantage enjoyed by CBS with respect to registration is an advantage of the CBS mechanical disc rather than an advantage of the CBS system, but only in a footnote does the Commission recognize that if an all-electronic receiver is substituted for the mechanical disc

receiver the registration problem at the receiver end is identical for the RCA and CBS systems. (Note 23) Not even footnote recognition is given, however, to the fact that if all-electronic apparatus were used in the CBS system at the camera as well as at the receiver, the registration problem is identical for both systems.

Color Fidelity

The Commission has stated that in using its tri-color tube RCA "suffers from the limitations as to color fidelity which are involved in the use of color phosphors rather than filters." (Par. 87) Whatever the difficulties may have been there is now no technical advantage in using color filters rather than color phosphors to produce excellent color fidelity. The green and blue phosphors always emitted light [fol. 344] closely approximating the desired primary colors. More recently, the same result has been accomplished with the red phosphors.

In its evaluation of the RCA and CBS systems with respect to color fidelity, the CBS system is scored high and the RCA system scored low because of the alleged superiority of the color reproduction of the disc apparatus over the color reproduction of all-electronic apparatus. This is an apparatus and not a system matter. No recognition is given to the fact that if RCA tri-color tube receivers are used by CBS to eliminate picture size limitations of the mechanical disc, any color fidelity advantage which it is alleged can be obtained through the use of disc receivers will be eliminated. The ultimate color fidelity obtainable with all-electronic apparatus is superior to that obtainable with disc appartus.

The use of mixed highs in the RCA system does not operate as a limitation on color fidelity. This is confirmed by the experience of the color printing industry. As the Condon Committee noted, detail in color printing is furnished by monochrome just as it is in the RCA system through the use of mixed highs.

Resolution

The Commission has erroneously concluded that the addition of color more than outweighs the loss in geometric resolution in the CBS color system. (Pars. 90, 143) The fact is that good resolution is one of the basic requisites of

a color system. Good geometric resolution is essential to a satisfactory picture and color does not constitute a substitute.

The Commission has stated that "in practice, the RCA resolution has suffered from . . . misregistration". [fol. 345] (Par. 91) Upon the only occasion when there was a check of resolution by members of the Commission's staff, the test pattern readings and the testimony of Mr. Plummer, its Chief Engineer, established that the RCA system successfully achieved the full resolution afforded by the test pattern used—resolution equivalent to that of the standard black and white system.*

Picture Texture (Structural)

The Commission has found that the texture of the RCA picture suffers from visibility of dot structure and "it appears" that if the dots are smoothed out, loss in resolution or contrast is likely to result. (Par. 97) Visible dot structure can be eliminated without appreciably impairing contrast or resolution.

Susceptibility to Interference

The Commission has concluded that the RCA color system "is much more susceptible" to interference than the present black and white system or the CBS color system. (Pars. 101, 136) This alleged susceptibility could exist only when the interference is within plus or minus 1/10 of a megacycle of the sampling frequency. This is unimportant since it can be virtually eliminated by circuit design if experience should show this is necessary.

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* Mr. Plummer's testimony was:

"Q. [By Mr. Heffernan] . . . when you get six separate readings [on the test pattern] that come up to 325, which is the optimum for that kind of a test pattern, is it not fair to infer from that that that is indicative that the [RCA] system can have horizontal resolution of 325 even though certain particular laboratory exemplifications of the apparatus on that day did not all have that figure?"

"A. [By Mr. Plummer] That is right . . ."

Adaptability and Convertibility

The Commission has implied that the black and white pictures produced from the CBS and RCA color systems [fol. 346] are similarly degraded. (Pars. 107, 143) The CBS black and white is degreded, but the black and white picture produced from RCA color transmissions is not degraded. It is of the same high quality as a standard black and white picture.

Equipment Considerations

The Commission's Report implies that the reduction in quality resulting from transmission of CBS color pictures over the coaxial cable is no greater than the degradation in black and white pictures over the cable. (Pars. 114, 143) The Commission's Report fails to state that the transmission of a CBS color picture over the coaxial cable imposes degradation on top of degradation. As a result the horizontal resolution of the CBS color transmissions over the coaxial cable is only 37% of standard black and white direct broadcasts. The Commission likewise fails to point out that CBS color signals transmitted over the cable and received on adapted black and white receivers will not have color to compensate, to whatever extent it can, for the 63% loss in resolution.

The Commission's consideration of the use of magnifying lenses in connection with CBS disc-type receivers is unrealistic and unwarranted in view of the lack of public acceptance of magnifying lenses.

The Commission's Report is both wrong and misleading in its treatment of receiver costs. In dealing with the RCA system it refers to RCA testimony of limited significance but fails to refer to significant RCA testimony. The result is to create a false impression with respect to the cost of RCA tri-color tube receivers..

In his testimony Dr. Engstrom used a 16″ set as illustrative. He quoted the price of a color set in the way it [fol. 347] would normally be given—including the kinescope. On this basis he said he was sure the price would "stay within the range of 25 to 50% more" than for a 16″ monochrome set.

In dealing with CBS type sets, the Commission refers to the cost of adapters and converters based on estimates which did not take into account the continuously adjustable

bracket standards now proposed for the first time by the Commission. Moreover, in stating an estimate of the cost of a color receiver, the Commission was so unrealistic as to give this for a 7" set—a size which has been obsolete for over two years.

The result is that the Commission has no proper basis for any findings as to cost figures for field sequential receivers of the type now proposed nor of the size now demanded by the public.*

The Commission's statements with respect to the RCA color receiver imply that it is a defect that receivers for the RCA color system must have a band pass of at least 3.6 megacycles, referring to the fact that many of the cheaper receivers today are built with a band pass narrower than 3.6 megacycles. (Par. 117) This cannot be regarded as a defect since, to the extent that receivers do not respond to the full 4 megacycle video signal, a waste of spectrum space results.

Commission's Conclusions

The Commission's Report is contrary to the technical testimony of some of the most eminent engineers in the electronics field. The Commission has assigned as the [fol. 348] reason for its disregard of this testimony the fact that in 1946-47 some of these same engineers supported the RCA simultaneous system. The record in this proceeding is perfectly clear that the color system advocated by RCA is its simultaneous system modified to permit operation in a 6-megacycle channel. The dot sequential aspect is simply part of the means whereby the 3 simultaneous signals are put in a 6-megacycle channel without loss of resolution. In view of this, the fact that these engineers have testified in support of RCA's system in these proceedings is entirely consistent and the Commission's rejection of their testimony is unwarranted.

In rejecting compatibility as a criterion, the Commission stated that it is of the opinion, "based upon a study of the history of *color development* over the past ten years",

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* As an example of the significance of size, the problems raised by 5(c) of the Commission's Second Notice of September 1 are of an entirely different order in sets with 16" and 19" tubes than they are for sets of 7" and 10", by virtue of the greater deflection angle in the larger tubes.

that from a technical point of view "compatibility . . . is too high a price to put on color". (Par. 123) To the extent that this implies that there has been even the opportunity for development work in color television for the past ten years, it is plainly mistaken. During a large part of that period, work in color television was displaced by the development of wartime applications of the electronic art.

The Commission recognizes that the CBS disc apparatus cannot produce a picture larger than that provided by a 12½ inch tube—the very minimum in public acceptance today—and gives this as one of its reasons for not adopting the CBS system now. But it does not lay down as a criterion the requirement that a color system's apparatus be free from such limitations in respect of picture size.

In its criteria, the Commission does not specify that the color system must not result in degraded resolution and decreased resistance to flicker.

[fol. 349] The Commission has stated that it should not by insisting upon compatibility deprive 40,000,000 American families of color television. There are nowhere near 40,000,000 American families living within range of television transmitters today and in view of the "freeze" and the time required to build additional transmitters, the extra time which may be needed for a compatible color system will not prejudice "40,000,000 American families". The Commission's professed solicitude for the unrealistic "40,000,000 American families" is to be contrasted with its disregard of the 10,000,000 owners of black and white receivers, upon which the whole television broadcasting industry depends.

The Commission has concluded that the RCA system must make use of "exceedingly complex" receivers. (Par. 134) The Commission's unwillingness to find that the RCA tri-color tube eliminates complexity in the RCA receivers rests in part on the fact that the tube "was not demonstrated until late in the proceedings." The RCA tri-color tube was demonstrated on April 6, 1950, and the demonstration by CBS of the effect of long persistence phosphors on flicker did not occur until April 26, 1950. However, the Commission has relied upon the later demonstration of long persistence phosphors in minimizing one of the principal limitations (flicker) upon the CBS color system.

The Commission's conclusion that the RCA receivers are "exceedingly complex" is not correct. In the early part of the hearing Mr. Fink had referred to equipment complexity in the RCA system. In April he testified that this had been eliminated by the RCA tri-color tube. In May Mr. Chapin, Chief of the Laboratories Division of the Federal Communications Commission, said that, on the [fol. 350] point of complexity, the issue was a stand-off between RCA and CBS.

The Commission stated that the RCA tri-color tube as demonstrated on April 6 had an inadequate number of dots. (Par. 134). The tube demonstrated on April 6 had 351,000 dots; the Commission was informed on July 31, 1950 by the RCA Progress Report that the number of dots in the RCA tri-color tubes had already been increased to 600,000.

The Commission has concluded that there is such great difficulty in maintaining the RCA studio and camera equipment in proper operating condition that it is "unlikely that the job could be done by an organization that does not have an extensive staff of research personnel and engineers at its disposal." Operation of the RCA studio and camera equipment does not require unusual engineering or technical skill. The Washington color broadcasts which have been on the air since last January have been carried on by operators from the regular WNBW staff—they have not been research personnel at all.

The substance of the findings of fact and conclusions which should have been made by the Commission on the basis of the record in the hearings on the color television issues are set forth in the proposed Findings of Fact and Conclusions filed by RCA on June 26, 1950. Reference is made to that document and to the RCA Statement in Reply to Proposed Findings of Fact and Conclusions filed by RCA on July 10, 1950 for further instances in which the Commission's Report is arbitrary and capricious and contrary to the evidence.

[fols. 351-352] Annex C

(Report of Condon Committee Follows)

81st Congress, 2d Session | SENATE | Document No. 197

THE PRESENT STATUS OF COLOR TELEVISION

REPORT

OF THE

ADVISORY COMMITTEE ON COLOR TELEVISION

TO THE

COMMITTEE ON INTERSTATE AND FOREIGN COMMERCE UNITED STATES SENATE

PRESENTED BY MR. JOHNSON, OF COLORADO

July 14 (legislative day, July 1), 1950.—Ordered to be printed, with illustrations

UNITED STATES
GOVERNMENT PRINTING OFFICE
69765 WASHINGTON 1950

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United States Senate,
Committee on Interstate and Foreign Commerce,
May 20, 1949.

Hon. E. U. Condon,
Director, National Bureau of Standards,
Washington, D. C.

My Dear Dr. Condon: The question of the present-day commercial use of color television has been a matter of raging controversy within the radio world for many months. There is a woeful lack of authentic and dependable information on this subject.

Hundreds of applicants for television licenses as well as those now operating television stations are vitally affected by its settlement. The capital investment involved in the installation of a television station runs into a tremendous sum. The operational costs of such a station are extremely high also. All of these expenses must be recovered through advertising. Those who are experienced in advertising believe that if color television were available now, attractive local advertising revenues could be obtained due to the strong consumer demand for it.

The Federal Communications Commission has declined to authorize commercial licensing of color television. It seems reluctant to indicate when and if it will act with respect to authorizing commercial licensing of color. As we understand it, the Commission must first fix minimum standards for color television before licensing can be undertaken, but it refuses to attempt to do so on the premise that color television has not been developed sufficiently for standards to be determined.

Accordingly, it is greatly in the public interest that a sound, factual ascertainment be had now whether or not minimum standards can be fixed today, or in the very near future, so that color television might develop and progress with complete freedom under the stimulus of commercial competition.

One unit in the industry has demonstrated color television 6 megacycles wide and asserts that if the Commission would allocate frequencies and license commercial operation, it could go ahead "tomorrow." Another large unit in the industry also, has demonstrated color television of varying width from 6 to 18 megacycles but believes that color is not yet ready for commercial operation; that much more experimental work must be done and field tests made before commercial licensing should be undertaken. Still another unit in the industry is said to be of the opinion that color television is several years away.

My objective, and the objective of the Senate Committee on Interstate and Foreign Commerce, is to encourage development of the radio art and to press for a Nation-wide, competitive television service in the public interest. Our committee sees television as a great new industry, not only providing new jobs and a new source of wealth but as the greatest medium of entertainment and diffusion of knowledge yet known to man. We believe that it has made great advances

but we are concerned that through delay in opening up the ultrahigh frequencies and holding up color until such time as some electronic experts believe that color has reached a state of perfection, a chain of circumstances will have been created which will tend toward monopoly control of the entire television art.

We are anxious, also, to reduce as much as possible any sharp impact on both station licensees and the general public, who already have invested one-half billion dollars in receiver sets, of any sudden but eventually necessary conversion to color. It is our belief that if both potential licensees and the set-buying public are given all of the facts now with respect to color television, less exploitation will ensue and less wasteful expenditures will occur.

Frankly, it seems to us that this is the time to obtain these facts and make them public. The Commission has in effect a "freeze" on further television allocations in the VHF band. It faces the problem of opening up the UHF band in order to provide sufficient channel space for a competitive Nation-wide television system. Now, when there is at least the probability that both bands may be opened simultaneously for allocation, is the time to make certain regarding the color television situation so that, if it is technically feasible, the Commission might also simultaneously open color to commercial licensing in either or both bands.

It has occurred to me, therefore, that at this juncture you could be most helpful in giving this committee sound, impartial, scientific advice. I am anxious that you individually, or in association with a small group of scientific persons of repute, none of whom are employed by or have any connection directly or indirectly with any radio licensee or radio-equipment manufacturer, shall investigate officially this matter for the committee.

Specifically, I would like you and your group to visit the laboratories of the Radio Corp. of America, Columbia Broadcasting System, Du Mont, and any others engaged in color television research and development; confer with their engineers; witness demonstrations; ask questions, all with the purpose of coming to a definite opinion as to the present stage of development of color television. Your inquiries will necessitate an evaluation of present-day practicability of color television: in short, can a satisfactory color television picture be broadcast today in the VHF and UHF frequency bands?

We are aware, of course, that both transmission and reception equipment is not now available on a commercial scale but that is not a controlling factor in whether color television should or should not be licensed, or stations allocated. We are also aware that undoubtedly experience and further experiment will result in the development of a better color picture but that, also, is not a factor in the evaluation we seek. We realize, as you, that color television today is as different from what it will be in perhaps 5 years as were the old crystal radio sets as compared with present-day radio receivers. It is not necessary that the art be fully developed for minimum standards to be outlined.

I am particularly concerned with resolving once and for all the charges that have been made that the advance of color television has been held up by the Commission for reasons difficult for us to understand, and I feel certain that a committee headed by so eminent a scientist as you will help resolve these doubts and questions which have been tossed about.

You will want, I assume, to confer with the engineers and laboratory personnel of the Federal Communications Commission as well as with the people in the industry. I feel certain that you will have the cooperation and willing assistance of the responsible officials of the industry in such a study, and I shall be pleased to ask them and any Government agencies who may be concerned to accord you and your group every assistance and cooperation.

I sincerely hope in the public interest that you will assume this difficult assignment. I shall be pleased to confer with you at your convenience.

Sincerely yours,

ED. C. JOHNSON, *Chairman.*

THE PRESENT STATUS OF COLOR TELEVISION

Chapter 1

SCOPE OF THE INVESTIGATION AND SOME BASIC CONCLUSIONS

1. Introduction

This report has been prepared at the request of the chairman of the Senate Committee on Interstate and Foreign Commerce. It represents an independent appraisal of the present status of color television in the United States and takes into account observations of the black-and-white television service now offered to the public as well as demonstrations of three color-television systems proposed for public use by Color Television, Inc., the Columbia Broadcasting System, and the Radio Corp. of America. The report is confined to technical factors, expressed so far as possible in nontechnical terms.

The report is organized as follows: Chapter 1 outlines the activity of the committee, describes the approach of the committee to its assignment, and sets forth some basic conclusions. Chapter 2 analyzes color-television service in general and lists the apparatus and performance characteristics by which competing color systems should be judged. Chapters 3, 4, and 5 describe, respectively, the three proposed color systems, in alphabetical order, viz, those of Color Television, Inc. the Columbia Broadcasting System, and the Radio Corp. of America. These chapters state the actual and potential performance of the systems, in terms of the characteristics listed in chapter 2. Chapter 6 consists of a comparison of the three color systems and the black-and-white system, and includes a tabular tally sheet on which the systems may be judged.

No recommendation for the adoption of a specific system is given, since the committee believes that the decision to adopt a system must include consideration of many social and economic factors not properly the concern of the technical analyst. It is hoped that the report will provide a comprehensive and understandable basis on which the technical factors may be considered in arriving at a decision.

2. Narrative of the committee activity

The Senate Advisory Committee on Color Television was appointed in June 1949 by its chairman, Dr. E. U. Condon, the Director of the National Bureau of Standards, in response to a request by Senator Edwin C. Johnson of Colorado, chairman of the Senate Committee on Interstate and Foreign Commerce. The letter from Senator Johnson to Dr. Condon requesting the investigation, dated May 20, 1949, precedes this report.

On May 26, 1949, the Federal Communications Commission announced that, at a hearing to be convened to consider expansion of the commercial television service, evidence would be taken concern-

ing the possibility of instituting a public color-television service. Excerpts from the FCC Public Notice No. 49-948 relating to the color-television aspects of this hearing are appended as annex A.

Meetings of the Senate advisory committee (hereinafter referred to as "the committee") were held August 3, 17-19, October 7-10, November 21-22, 1949, January 19, 20, February 1, 20, 23, March 11, 14, April 26, May 22, July 5, 6, 1950. During these meetings, demonstrations of color television were attended by two or more members of the committee as follows: CTI system, February 20, 23, March 14, 1950; CBS system October 6-10, November 21-22, 1949, January 20, February 1, 23, April 26, 1950; RCA system, October 6-10, November 21-22, 1949, January 19, 23, 1950; Hazeltine demonstration, May 22, 1950. These demonstrations included the comparative demonstrations of the color systems before the FCC held November 21-22, 1949 and February 23, 1950, at which all members of the committee, or designated alternates, were present.

At its meeting of November 21, 1949, the committee discussed the question of the basic terms of reference of the report, particularly regarding the availability of additional channels not then contemplated by the FCC proposals. As a result of this discussion, an inquiry was prepared and forwarded to Senator Johnson as of February 2, 1950. A copy of this inquiry is appended hereto as annex B.

Shortly thereafter, the formation of the President's Communications Policy Board was announced. In view of the contemplated activity of this Board, Senator Johnson advised the committee to proceed within the terms of reference proposed by the FCC, namely, to consider channels in the very-high-frequency (VHF) band from 54-88 and 174-216 megacycles, and channels in the ultra-high-frequency (UHF) band from 475 to 890 megacycles. Senator Johnson's reply is appended as annex C.

At its meeting of March 11, 1950, the committee met with Senator Johnson and discussed matters pertinent to the report. The final report, approved unanimously at the meeting of the committee, July 5-6, 1950, is presented herewith.

3. Terms of reference of the report

(*a*) *The 6-megacycle radio-frequency channel.*—This report is concerned only with color-television systems intended for a 6-megacycle radio-frequency channel; that is, a channel equal in width to that now assigned to black-and-white stations. Since color systems of superior performance have been demonstrated using channels wider than 6 megacycles, the justification for confining this report to the 6-megacycle channel is stated at the outset.

As shown in greater detail in chapter 2, the choice of the channel width in a television system is necessarily a compromise between quality and quantity; quality of the reproduced television image on the one hand and quantity of television service on the other.

If the radio channel width were doubled, a clearly perceptible improvement in the quality of the image should be apparent, but the number of channels available would be halved, thereby greatly reducing the possible number of stations.

Moreover, as the width of the channel is progressively increased, the corresponding improvement in picture quality apparent to the observer under normal viewing conditions becomes less pronounced. There is, in other words, a law of diminishing returns that ultimately

affects the attempt to improve image quality by increasing the width of the channel. On the other hand, no such diminishing law affects the relation between channel width and the number of channels. Each time the channel width is doubled, the number of channels is halved, and this law holds without diminution as the channel width is increased.

Evidently a point is reached, as wider channels are considered, at which the slight improvement in image quality afforded by a substantial increase in channel width is not worth the reduction of service that would be entailed. The optimum channel width must be chosen, therefore, by a body qualified to judge that combination of quality of image and quantity of service which best serves the public interest.

This judgment has been entrusted by statute to the Federal Communications Commission, which established the 6-megacycle channel for black-and-white television as early as 1937. This channel width provides an image quality roughly comparable to that of 16-millimeter home motion pictures, and allows 12 channels to be assigned in the very-high-frequency spectrum, due account having been taken of the needs of other services.

When a color-television service is considered, the optimum compromise between quality and quantity, similarly determined as meeting the public interest, does not necessarily lead to the same value of channel width. In fact, the addition of color to the image brings about a degradation of certain other qualities in the image (particularly pictorial detail and freedom from flicker, see ch. 2) when the channel width is unchanged. To avoid degradation of these qualities in the color image, a wider channel must be assigned.

In the face of this fact, a mitigating circumstance has appeared, in the form of a new development (known as dot interlace, explained in ch. 2) which is capable of substantially improving the pictorial detail of the television image, without requiring any increase in the width of the channel.

Specifically, when dot interlace is adopted in a color-television system, the technique can provide a color image whose pictorial detail is substantially equal to that of the black-and-white images currently rendered to the public. This fact implies that color service, capable of being rendered on a 6-megacycle channel, may achieve a quality generally as satisfactory as that of current black-and-white broadcasts.

Another factor affecting the choice of channel widths is an economic one, relating to the investment by the public in black-and-white television receivers when color television is first offered as a regular public service. If the investment is substantial, when compared to the ultimate per capita investment to be expected in the then foreseeable future, it is desirable that after any change or extension of the television service, the service can be used with then-existing receivers with a minimum of expense, inconvenience, and/or degradation of the quality or quantity of the service. If the new service operates on channels wider than 6 megacycles, existing receivers cannot use the new service.

Based on the foregoing analysis, the committee concludes that the allocation of 6-megacycle radio-frequency channels for color television is the proper compromise between the quality and the quantity of the color service.

(*b*) *Comprehensive nature of systems considered.*—In restricting its consideration to three color-television systems, the committee is aware that certain other systems, known to the members, might have been considered. The report is confined to these three systems, not merely because they are the ones actively proposed at present, but rather because they comprise, as a group, all of the basic types of sequential color systems.

Television images, as outlined in greater detail in chapter 2, consist of picture elements (dots) arranged along lines, the lines being assembled to cover the field (the picture area). A succession of fields is transmitted to create the illusion of continuity and motion in the image. The dot, the line, and the field are then the three basic elements of a television picture. No matter how the picture is analyzed in the television camera or synthesized at the receiver screen, the process of transmission can always be described in terms of these three elements.

It is most fortunate, therefore, that the systems of color television actively proposed are based respectively on these three attributes of the image. The RCA system is a dot system, since the color is assigned to successive picture elements, or dots, of the image. In the CTI system, a line system, the color is assigned to successive lines of the image. The CBS system is a field system, the color values being assigned to successive fields of the image. Other color systems (notably the simultaneous system developed in 1946 by RCA but discontinued in favor of the dot system) are known, but they are difficult, if not impossible, to adapt to a six-megacycle channel.

> If, therefore, only six-megacycle systems are to be considered, the committee concludes that the color-television system ultimately adopted must be either a dot-sequential system, a line-sequential system, or a field-sequential system. No other methods need be considered, in the light of present or foreseeable technical developments.

(*c*) *Mutually exclusive nature of the color systems.*—Because the three color systems herein discussed are based on fundamentally different aspects of the television image, they are to a very large extent mutually exclusive, so far as public service is concerned. All use the 6-megacycle channels, and in many other respects are similar (each uses the same type of sound system, for example). Each, however, is fundamentally different from the others in the way in which the color values are distributed among the dots, lines, and fields of the image, and this difference is so profound that the receivers for one system cannot be converted to another except at considerable expense.

At the present stage of the art, a universal receiver, capable of receiving transmissions of all three types, would represent three separate receivers in a single cabinet, with certain elements in common. Changing the connections of the common elements, to convert from the dot-system to the line-system or to the field-system of reception, would involve a highly complicated and vulnerable mechanism. Moreover, the compromises inherent in the design of such a universal receiver would most certainly impair the performance of at least one system and perhaps of all three systems.

Past experience, notably in Great Britain in 1936, with multiple standards of television transmission has proved that such action encourages a portion of the viewing public to purchase equipment which

loses its value when the final decision is made among the multiple standards. The decision can be made, and should be made, on the basis of analyses and tests conducted prior to the inauguration of the public service. Moreover, these analyses and tests are well under way, and the final decision can be made without unwarranted delay. But any authorization of color-television transmission on a multiple-standards basis is a guaranty of confusion that may well impose a much greater delay in the development of the color-television service.

The committee concludes that one and only one of these systems should be licensed for service to the public and that therefore the decision among the dot-, line-, and field-systems must be made in advance of the introduction of a color television service.

4. Summary

In summary, the committee bases this report on the following basic conclusion:

1. A 6-megacycle radio-frequency channel is adequate for color-television service and represents a proper compromise between quality and quantity of service.
2. The three systems of color television herein described comprise all of the basic systems of color television which need be considered for a 6-megacycle channel.
3. The three systems are mutually exclusive. One, and only one, of these systems must be chosen in advance of the inauguration of a public color television service.

Chapter 2

COLOR TELEVISION PRINCIPLES

5. Natural vision versus television

In natural vision, the scene before the observer is focused on the retina of the eye, which contains millions of tiny light sensitive elements, all of which are continuously exposed. These retinal elements are connected to the optic nerve, which comprises hundreds of thousands of separate fibers, each of which is capable of carrying a part of the visual impression to the brain. In this manner all parts of the scene are apprehended simultaneously.

When an artificial medium, such as motion pictures or television, is interposed between the scene and the eye, it is not practicable to imitate the continuous nature of the actual scene. Rather, it is necessary to present to the viewer a rapid succession of still pictures, each differing very slightly from the ones preceding and following it. In motion pictures, this is done by printing a succession of pictures on a strip of film and passing the film through a projector. Each picture on a movie film is a comprehensive still picture of the whole scene. In motion pictures, therefore, the camera apprehends the whole scene at once, but it does so in discontinuous fashion, one still picture at a time.

In television, a similar succession of still pictures is transmitted, but it is not practicable to transmit the whole area of each still picture at once. This would require hundreds of thousands of separate cable or radio circuits, corresponding to the hundreds of thousands of separate fibers in the optic nerve. Any channel of an electrical communication system using telephone lines or radio waves can transmit

only one thing at a time. Therefore the picture must be analyzed into a finite number of picture elements whose light intensity must be converted into signals one after the other, sent over the communication channel, and reassembled on the viewing screen in the proper position, all within the time normally used in a motion picture for showing one frame. The number of picture elements which must be distinguished in television is dependent upon the detail desired.

If the processes of dissecting and reassembling are carried out very rapidly the whole receiver screen appears to be illuminated simultaneously.

6. Television scanning: "Reading" the content of the scene

Television images are dissected and reassembled by a process known as "scanning," a term which arises from the similarity of the process to the action of the eye in scanning pages of printed matter. The eye reads from left to right along the first line of type, then returns rapidly to the beginning of the next line, scans it, and so on until the bottom of the page is reached. The page is then turned, and the process is repeated on the next page.

In a televised scene, corresponding to the individual letters of print are rapid or gradual variations in light and shade, depending upon the nature of the scene. These variations are arranged in horizontal lines, like lines of print, and the lines are arranged parallel to one another, filling the picture area. In the television camera the variations along the uppermost line are explored rapidly from left to right, and signals are generated which correspond to the degree of light or shade along the line. When the first line is thus scanned, another line below the first is similarly covered, and so on, until the bottom of the picture is reached. In a communication system the signal cannot change abruptly from one value to another, and the shortest distance along the line which can be made to change from white to black is called a picture element. The shorter this distance the greater is the detail which can be transmitted, but the greater are the requirements on the system, particularly the wider is the band width which must be allocated to the communication channel. In some cases these picture elements may be made up of dots definitely located along the lines, but in the present black and white system variations may start or stop at any point and no dot structure is observable, although the line structure always is. However, for purposes of explanation these picture elements will be generally referred to as dots.

Like the lines of print in a double-spaced typewritten page, each line of elements is separated from the line above it and the line below it by a blank space of the same height as the line. The blank spaces are filled in during the next successive scanning of the picture area. The two sets of lines are thus "interlaced" one within the other. As these two sets of lines are scanned, all of the light and shade values, over the whole area of the picture, are translated into a succession of electrical counterparts. The picture is scanned in two sets of interlaced lines, rather than in one set of consecutive lines, in order to minimize flicker in the image. This is explained in section 8.

At the receiver, a spot of light moves across the picture screen in the same scanning motion. Acting under the control of the broadcast station, the spot changes in brightness as it moves along each line

and thus re-creates the light and shadows of the original scene. Since the light spot on the viewing screen moves in precise step with the scanning process at the television camera, each dot of light falls in its proper place, and has its proper value of light or shade.

This description of scanning shows how important it is that the operation of the television system be standardized. Once the number of lines and the number of pictures per second have been established it is essential that all receivers be capable of operating with that number of lines and that number of pictures per second. Any change in the scanning standards adopted for the transmitter thus requires an exactly equivalent change in the scanning process at each of the many millions of receivers in the hands of the public.

7. Pictorial detail: How many dots in the picture?

The choice of scanning standards starts with this basic question: How many dots are required in the whole picture area to reproduce a picture of acceptable quality?

If there were no economic limitations, and if the radio spectrum was limitless, it might be desirable to transmit a picture containing many millions of dots. Thus an 8-by-10-inch printed photoengraving of the highest quality (150-line-per-inch halftone, printed on high-gloss paper), contains about 2,000,000 dots. Such a picture can be examined closely by the unaided eye, without the dots themselves becoming separately visible.

In television and motion pictures, it is not necessary to examine the picture minutely. When a performance is to be viewed continuously for many minutes or hours, in fact, it is necessary that the whole picture area be contained within such a field of view as to avoid excessive movement of the neck or eyes. For example, most people find it uncomfortable and fatiguing to view continuously a picture 1 foot high from a distance less than 3 feet. This ratio of viewing distance to picture height applies equally well with other picture sizes; i. e., the minimum viewing distance, to avoid excessive fatigue, is generally taken to be three times the height of the picture. Many individuals cannot look for long periods at a picture unless it is viewed from a considerably greater distance than this, say five to eight times the picture height. These points are indicated by the location of the seats chosen in a motion-picture theater by patrons who have a free choice.

When the image is to be viewed at a distance greater than three times the picture height a pictorial detail of several hundred thousand dots suffices, as against the millions of dots that would be required for closer inspection. If a larger number of dots were used, the excess would be wasted since the eye cannot perceive the additional detail from a distance.

This limit on required detail has led to the choice of various sizes of motion-picture film. Professional 35-millimeter film, as commonly projected in motion-picture theaters, has a pictorial detail equivalent to about 1,000,000 halftone dots. The 16-millimeter movie film, used by the advanced amateur, has the equivalent of 250,000 halftone dots in the picture area, when film and projector are in first-class shape. The average performance of 16-millimeter home-movie film and projectors is such, however, that the effective pictorial detail seldom exceeds the equivalent of 200,000 dots. The smallest movie

film currently used is the 8-millimeter size. This film has the equivalent of about 50,000 halftone dots in the picture area.

The pictorial detail offered by various motion-picture systems, professional and amateur, is a compromise. The upper limit is set by the cost of film and processing, cameras, and projectors. The lower limit is set by the reactions of the viewer, who objects to an image having so little detail that it is incapable of portraying a wide variety of subjects satisfactorily. All those who have viewed 16-millimeter and 8-millimeter movies of the same subject matter are well aware of the greater sharpness of the larger film. In payment for the superior performance of the 16-millimeter system, approximately four times as much money must be paid for film and processing for a given period of viewing time, relative to the 8-millimeter type. Accordingly, economic factors have given the 8-millimeter film a commanding position in the amateur-film market. At the other end of the scale, movie theaters employ virtually nothing but 35-millimeter film to meet the high standard required for elaborate and expensive productions.

In television, a similar compromise must be found, since it is expensive to set up a television system having too much detail in the image. The expense resides not only in the extra cost of transmitting and receiving equipment but also in the extra space occupied by the television channels in the radio spectrum. In a given portion of the spectrum, for example, the number of channels which can be accommodated varies in inverse proportion to the number of picture elements in the image, all other factors remaining unchanged. Thus a change from a television system approximately equivalent to 16-millimeter home movies (200,000 dots) to one equivalent to 35-millimeter professional movies (1,000,000 dots), would force a reduction in the number of channels in the ratio of 5 to 1. For the sake of completeness, it should be mentioned that, on the basis of geometrical resolution alone, a 200,000-dot motion-picture system would be superior to a 200,000-dot television system, because the line structure is not present in the motion picture.

Faced by this conflict between quality (pictorial detail) on the one hand, and quantity (number of stations and choice of programs) on the other, the Federal Communications Commission in 1941 adopted for public television broadcasting a black-and-white system having about the equivalent of 200,000 halftone dots in the picture area. This choice appears to have merit, because it follows the standard of the best visual medium of entertainment hitherto used in homes, the 16-millimeter home-movie system. More fundamentally the 200,000-dot television system permits the picture to be viewed at a distance as close as four times the picture height, without the picture structure's becoming too evident. This viewing distance is close to the minimum value of three times the picture height, set by the fatigue factors previously discussed.

When it is decided that the television picture should be equivalent to 200,000 halftone dots, it is necessary to select the number of lines and the number of dots per line. This is not a critical matter. For example, a picture of 400 lines, each having 500 dots, would provide a 200,000-dot picture ($200{,}000=400\times500$). A picture having 500 lines, each containing 400 dots, would serve equally well. The present black-and-white system employs 525 lines, about 490 of which are

actually visible on the screen, and each line has the equivalent of about 420 dots along its length. As previously stated, the 490 visible lines are actually scanned in two sets of 245 lines each, one set interlaced within the other.

Experience with the 525-line black-and-white system since 1941 has shown that it provides an adequate basis for a public television service, so far as pictorial detail is concerned. But this is not to imply that additional detail would not be desirable if it were available without excessively reducing the quantity of service. For this reason, the introduction of dot interlace to the black-and-white system is being considered. This recently developed technique would increase the pictorial detail of the black-and-white image from 200,000 dots to something over 350,000 dots, without any increase in channel width.

Before leaving the question of pictorial detail, it must be emphasized that this aspect of television-system performance is capable of a considerable degree of misinterpretation in comparing the merits of different proposals. The difficulty arises from the various types of subject matter which may be portrayed by television.

When a scene is viewed in a close-up shot, as for example when the face of a performer fills the whole screen, not much pictorial detail is required. To show the essential features and details of a face it is not necessary to use more than 50,000 dots, as experience with the 8-millimeter movie system has amply demonstrated. When, however, it is desired to show the whole area of a baseball diamond, or some other equally extensive subject, the requirement for pictorial detail is very much larger. In fact 200,000 picture elements may then be insufficient to show more than the bare outline of the individual players.

Since a television system is called upon to depict both close-ups and long shots, sufficient pictorial detail must be provided to take care of the long shots, despite the fact that a large part of the detail is wasted when close-up shots are being transmitted. A test of a television system which comprises only close-up shots does not reveal the pictorial-detail limit of the system. Such tests must show the whole range of subject matter for which the television system is intended.

Since the appreciation of pictorial detail is a highly individual reaction of the viewer, it is unlikely that complete agreement on this aspect of system performance will be reached by all participants in a test. But it is possible to state categorically the effect of pictorial detail in the following terms:

Consider a subject viewed in a close-up shot, and suppose that the camera moves back from the subject so that the close-up shot gradually becomes a medium-length shot and finally a long shot. At some point, as the camera recedes from the subject, a given viewer will find that the pictorial detail becomes inadequate and the portrayal is unsatisfactory. This is the point at which the pictorial detail of the image becomes the limiting factor, for that particular observer.

If now the picture detail in the television image is increased, the area viewed by the camera can be increased in the same proportion, without exceeding the critical limit set by that observer. Suppose, for example, that the number of dots is increased four times, from 50,000 to 200,000. Then the camera can take into view an area four

times as great, with the same degree of visual satisfaction. In concrete terms, if the face of one actor can be shown, with a given degree of satisfaction, on a screen of 50,000 dots, four actors can be shown with the same degree of satisfaction with a screen of 200,000 dots; if the action covering 1,000 square feet of a basketball court is portrayed satisfactorily with a 50,000-dot image, action covering 4,000 square feet may be portrayed with the same satisfaction with 200,000 dots.

Any limitation in the detail of the television image constitutes, therefore, a limitation on the program director with respect to the area which he can pick up with a given degree of satisfaction. If the pictorial detail is low, say, 50,000 dots, the cameraman must use close-up shots almost exclusively; whereas if 200,000 dots were available, medium shots could be used with the same degree of satisfaction. Finally, if very high detail were available, say a million or more dots, long shots would display the same degree of visual distinction as medium shots and close-ups.

It follows that the flexibility with which the program director can use lenses and cameras is intimately tied up with the detail provided in the image, and any restriction on pictorial detail implies a restriction on the use of the camera. It is true that this restriction can be circumvented in many types of programs by rapid switching from camera to camera, each showing a close-up shot. In athletic contests and other large-scale presentations, however, the restriction on viewing angles may prevent the viewer from following the over-all aspect of the action. This limitation is clearly evident in telecasts of football and hockey, but is much less noticeable in the confined arena of a boxing or wrestling match.

The technical term for pictorial detail is "resolution," because this quantity represents the ability of the television image to resolve the fine details of the scenes it depicts. As we have seen, resolution is measured by the total number of equivalent halftone dots in the image. The number of equivalent dots along each line (conventionally measured as the number of dots in a distance equal to the picture height) is the "horizontal resolution." The number of dots resolved at right angles to the lines is known as the "vertical resolution." As outlined in the following chapters of this report, resolution, measured in the horizontal and vertical directions, is one of the basic criteria by which the proposed color-television systems must be compared.

8. *Image continuity: How many pictures must be transmitted per second?*

The second question in the choice of scanning standards is the number of complete pictures to be sent per second. In considering this question it is necessary to have clearly in mind the meaning of the terms "field" and "frame." In section 6 it was pointed out that the television image is scanned in two sets of lines, one interlaced within the other. One set of these lines, having blank spaces between lines, is known as a field. The lines of one field cover only one-half the area of the picture. The other half of the area (the space between the lines) is filled in by the lines of the next successively scanned field. Hence all points in the picture have been covered when two successive fields have been scanned. Two successive fields, comprising all the lines in the image, are known as a frame.

To insure continuity in the motion of the image, it is necessary that the fields succeed one another at a rapid rate. If the fields are presented at a rate slower than about 15 per second, the apparent motion in the image will be disjointed or "jerky." This corresponds to running a motion picture film through a projector at too slow a speed.

In practice the rate of scanning the successive fields must be much higher than this minimum value of 15 per second, because of another effect known as flicker. Flicker appears because the light on the screen is cut off between the successive pictures. If the rate of scanning successive fields is too low, the light on the screen will appear to blink on and off in a manner which is annoying to watch and induces severe visual fatigue. If the successive fields are scanned at a sufficiently rapid rate, however, the sensation from one picture persists throughout the dark interval between fields and the screen appears as if it were continuously illuminated.

The brighter the television image, the more perceptible is the flicker. Hence, in deciding how many fields must be scanned each second, it is necessary to decide how bright the picture must be, and then choose a field rate high enough to avoid flicker at that level of brightness.

Different compromises have been adopted in this respect in different countries. In Great Britain, the pictures are scanned at a rate of 50 fields per second, whereas in the United States, in the black-and-white system, they are scanned at 60 fields per second. The brightness at which flicker is perceptible goes up very much faster than the increase in field rates, with the result that the American rate of 60 per second permits pictures to be about 6 times as bright as the British pictures. In consequence, British receivers must be viewed in a darkened room, whereas most American receivers can be viewed satisfactorily in rooms illuminated by direct daylight.

Two types of flicker must be distinguished in comparing the performance of color television systems. The first is "large-area flicker", which applies to the whole area of the image, or to any bright part of the image occupying a substantial portion of the field of view. The more closely the image is viewed, the larger is the portion of the field of view occupied by the bright portions of the image, and the more noticeable is the large-area flicker effect.

The second type of flicker, known as small-area flicker, appears in areas having the size of a few picture elements or the width of a few scanning lines. This type of flicker is most noticeable on close inspection of the image, but it may be apparent at normal viewing distances under certain conditions.

One form of small-area flicker applies to individual scanning lines. We have noted that each picture is scanned successively in two sets of lines, one set interlaced within the other. Hence any one line in the image is illuminated only half of the time, and the flicker rate which applies to a single line is accordingly half that applying to the image as a whole. This low flicker rate gives rise to the so-called "interline flicker" and "line crawl". Interline flicker manifests itself as a blinking of thin horizontal lines in the image, such as the roof line of a house. Line crawl is an apparent motion of the lines upward or downward through the image, due to the successive illumination of adjacent lines in the picture, particularly in bright parts of the image.

Flicker can be controlled either by dimming the image or by increasing the rate at which the successive fields are scanned. Both methods of flicker control are subject to severe limitations. If the image is dimmed too far, the fine detail in the image cannot be perceived by the eye, and eyestrain results. Also, even at considerably brighter levels than the eystrain limit, it is necessary to darken the room to secure accurate rendition of all the shades of gray (in a black-and-white picture) or all the saturations of color (in a color picture). On the other hand, if the picture-scanning rate is raised too high, the spectrum space required by the signal becomes exorbitant, as explained in section 10, below. The choice is essentially a compromise. Experience has shown that rates between 48 and 60 fields per second are required to produce flicker-free pictures of adequate brightness.

In passing, it should be noted that the picture-scanning rate is sometimes expressed in frames per second. Since a frame contains two scanning fields, the frame rate is one-half the field rate. Thus the 60-field-per-second rate of the American black-and-white system may also be stated as 30 frames per second. The most useful term, applicable to both black-and-white and color systems, is the rate in fields per second, and this term is used in this report unless specifically stated otherwise.

9. Channel width: How many megacycles for a television station?

The channel width required by a television station is determined directly by the scanning specifications described in the preceding paragraphs; namely, the number of equivalent dots per picture and the number of fields transmitted per second.

The relationship between these quantities can be traced as follows: From section 7 we recall that the standard black-and-white picture corresponds to about 200,000 dots, and that these dots are distributed in two sets of interlaced lines. One set of the interlaced lines (one field) thus encompasses about 100,000 dots. From section 8, we recall that the fields are transmitted one after the other at a rate of 60 per second. Nominally, then, 100,000 dots must be transmitted in one-sixtieth of a second. Actually, since a portion of the lines is not visible in the picture the time available is about one-eightieth of a second. Consequently, the rate of transmitting dots (100,000 of them in one-eightieth of a second) is about 80 times 100,000 or 8,000,000 dots per second.

To transmit picture dots at a rate of 8,000,000 a second, it is necessary to employ a channel width of at least 4,000,000 cycles per second (4 megacycles). This band width of 4 megacycles is required for the picture alone and is referred to as the video channel. In addition to this 4-megacycle minimum requirement, channel space of about 0.2 megacycle must be allowed for the sound transmission, and additional space must be allowed to prevent mutual interference between the picture and sound signals of the station. Finally, a substantial amount of additional space (about 25 percent) must be allowed to permit proper operation of the television transmitter and receiver (to permit "vestigial side-band" operation). When all these requirements are added, the radio-frequency channel width required for transmitting picture dots at a rate of 8,000,000 per second, plus associated sound, is 6 megacycles.

The foregoing discussion shows that the channel width is determined fundamentally by the number of picture elements (dots) in each field multiplied by the number of fields transmitted per second. If the number of dots were increased from 200,000 to 400,000 per picture, the channel width would have to be doubled. Similarly if the number of fields per second were increased from 60 per second to 120 per second, the channel width would have to be doubled. If both the number of dots and the number of fields per second were doubled, the channel width would have to be quadrupled.

When the channel width is fixed at 6 megacycles, as is assumed throughout this report, and in the absence of dot interlace, the number of dots can be increased above the 200,000-dot limit only if the number of fields per second is correspondingly reduced below the 60-per-second figure. Alternatively, the number of fields per second can be increased only if the number of dots is proportionately decreased.

The dots represent pictorial detail, and the field rate determines the brightness at which flicker becomes apparent. Hence pictorial detail can be increased only at the risk of incurring flicker, and flicker can be controlled only by incurring a loss in pictorial detail, once the channel width and picture brightness have been decided upon.

The conflict between pictorial detail and flicker has occupied the center of the stage in television development for many years. One result of this conflict is the division of the lines in a television picture into two groups, one interlaced within the other. This technique of "line interlace" was developed as early as 1934 to reduce flicker while maintaining the pictorial detail at a satisfactory level. In line interlacing, the area of the image is illuminated twice while the pictorial detail (200,000 dots) is laid down only once. While interlacing introduces interline flicker and similar small-area defects, these faults are worth accepting in favor of the general reduction of flicker, and the permissible brightening of the picture.

Much more recently (first announced publicly in 1949), an extension of this principle known as "dot interlace" was developed. In dot interlace, the picture elements along each line are arranged with blank spaces between them. In other words, they are actual dots, and the blanks are filled with dots on the next scanning of that line. When added to the line interlace just discussed, the dot-interlace system permits the area of the picture to be illuminated four times while the pictorial detail is laid down once. When the frequency of illumination is maintained at 60 fields per second, dot interlace plus line interlace thus permits all the pictorial detail to be laid down in one-fifteenth second (actually about one-twentieth second when the blanked-off portions of the lines are taken into account). Dot interlace therefore permits 400,000 dots to be accommodated in the picture as contrasted with 200,000 dots when only line interlace is used.

10. Color reproduction: The role of primary colors

The addition of color values to a television picture involves the reproduction of the thousands of different colors which the eye can distinguish. This seemingly formidable task is vastly simplified by the fact, established in Newton's time, that all colors can be very closely represented by combining just three colors, known as primary colors.

There are two types of primary colors. When the reproduction is effected with layers of colored material, one on top of another, through

which light must pass in succession, the so-called "subtractive primaries" must be used to obtain a satisfactory range of mixture colors. The subtractive primaries are red, blue, and yellow. These are the familiar primary paint colors known to students in elementary school. Subtractive primaries are used in oil and water-color paintings, in color printing, and in color photography (prints and transparencies). In color printing and photography, the primary colors used are a bluish red ("magenta"), a greenish blue ("cyan") and a greenish yellow. These subtractive primaries are the ones most commonly known to the public.

In color television, the reproduction is not effected with layers of colored material one over the other, but rather consists of individual lights of the primary colors presented one after the other in time sequence. For this type of color reproduction, the so-called "additive primaries" must be used. The additive primaries are red, blue, and green. If pieces of red glass and green glass are placed one beside the other (not one on top of the other) and white light is passed through them in such a manner that the red and green light thus formed falls on the same area of a viewing screen, the combined light will have a yellow color. If red, green, and blue glasses are similarly employed, the combined light on the screen will appear white, or near white.

With these primaries combined in proper proportions it is possible to reproduce any of the hues of the visible spectrum, plus purples which do not appear in the spectrum, plus all the shades of gray from white to black, as well as mixtures of the above. With only three primary colors it is not possible to reproduce all the spectrum colors exactly, but the color match can be made so close that only simultaneous inspection of the original color and the reproduction will reveal the difference. Experience with various types of color photography has shown, in fact, that a highly realistic rendition of natural colors can be achieved with three properly chosen primaries.

When only two primary colors are used, the rendition is very much less realistic. The primaries customarily used in the two-color process are a red-orange and a green-blue. With these, it is not possible to reproduce a pure (saturated) red, a pure blue, a pure yellow, or a pure green. Some improvements have been obtained by making the two primary colors change with brightness, but even so a system of such limitations cannot properly reproduce the colors in nature. For this reason, two-color processes have not been widely employed in motion pictures, nor have they been proposed for public color-television service. All of the color-television systems discussed in this report use the three additive primary colors, red, green, and blue.

Since at least three primary colors must be used to achieve realistic color reproduction, it follows that three color images must be transmitted by a color-television system. The three color images are transmitted in sequence, hence the name "sequential color television system." In the dot-sequential system, the primary colors are assigned to successive dots of the image. In the line-sequential system, the primary colors are assigned to successive lines of the image. In the field-sequential system, the colors are assigned to successive fields of the image.

The manner in which the colors are interspersed is discussed in detail in the following chapters relating to the three systems. Here it suffices to say that three separate images, one in each of the primary

colors, must be dissected in a particular sequence at the transmitter and reassembled in the same sequence at the receiver. The dissecting and reassembling processes are performed so rapidly that the primary colors are not separately perceived one after the other, but appear to the observer to blend or "fuse," as though they existed simultaneously.

Thus, while it is true that only one primary color is actually present on the receiver screen at any one instant in each of the three sequential systems here described, persistence of vision causes the picture screen to appear as if all three primary colors were present simultaneously throughout the area of the screen. We may then conclude that a color television image is equivalent to three images superimposed one on top of the other, each image being made up of light of one of the primary colors. As we shall see later, in each of the proposed systems the color images may be somewhat less detailed than the equivalent black-and-white image. But this is a difference merely of degree. In principle, a three-color television system employs the equivalent of three images, each depicted in light of one of the primary colors.

An important implication of this principle is this: All other factors being equal, the video channel occupied by a three-color television system must be three times as wide as that required for an equivalent black-and-white system. A color system equivalent in pictorial detail to the black-and-white system must transmit three images, each containing 200,000 dots, and all these images must be transmitted in the same time as that of one image in the black-and-white system. Hence the rate of transmitting picture elements (dots) in color is three times the rate in black and white, and the video channel width must be trebled to accommodate the transmission.

If a color-television system is to be fitted into a 6-megacycle channel, something must be sacrificed. Either the dots must be reduced in number, thereby reducing the pictorial detail, or the number of scanning lines must be reduced, thereby again reducing the pictorial detail, or the rate of scanning the fields must be reduced, thereby incurring flicker unless the picture brightness is dimmed by a substantial amount, or the number of fields per color picture must be increased, thereby increasing the blurring of motion. Some such compromise has been adopted in all three of the proposed color systems. The nature of the compromise, and its effect on the over-all image quality, is an important basis on which the systems must be compared.

The fact that three separate, apparently superimposed, images are involved in a color-television system gives rise to several potential sources of trouble. The first is "improper registration". The three primary-color images must be precisely the same size, have precisely the same shape, and must appear to lie one directly over the other if the color reproduction is to be accurate. Lack of registration is familiar in color printing. It occurs when the impression of one printing plate is out of position with respect to the other impressions. The outlines of objects are thereby blurred, the fine detail of the image is obliterated, and objects are outlined with color fringes.

Considerable care is required in the design and operation of a color-television system to secure proper registration. The three types of systems described herein employ different methods to secure registration, and their performance in this respect differs, as outlined in chapter 6. In particular, the field-sequential camera has at present

better performance in this respect than the dot- and line-sequential cameras.

The second source of difficulty, rooted in the sequential nature of a color-television image, is known as "color breakup". When the eye moves while viewing a color-television image, either casually or in following the motion of the image, the successive fields laid down on the screen occupy slightly different positions on the retina of the eye. If each successive field is displayed in one primary color, as in the field-sequential system, the separate primary colors are then visible in the form of fringes around the outlines of objects. This effect is present only in the field-sequential system, since in the dot- and line-sequential systems the color-switching rate is many times greater. Fortunately, the majority of observers possess, or soon acquire, a substantial tolerance for the color-breakup effect, under normal conditions.

The third effect is "color fringing". This occurs when a rapidly moving object is televised in color. If the object has color components in more than one primary (as do the vast majority of objects), and if the object is scanned in successive fields of different color (as in the field-sequential system), the object will be scanned in one color on one field and in another color on the next successive field. If the object is moving rapidly, its position on the screen will have changed between the successive scannings, and the object will appear fringed with color or, if the motion is very rapid, as several objects in different colors. Like color breakup, color fringing does not occur to a noticeable degree in the dot-sequential and line-sequential systems, since the color-switching rate is many times greater.

11. Color fidelity: How true is the color reproduction?

It is evidently of paramount importance that the reproduced colors be sufficiently faithful copies of the original colors to induce a sense of realism in the observer. A first requirement of faithful color rendition is that the primary colors employed at the receiver are chosen to cover a suitably wide gamut of colors. Since a free choice of phosphors and color filters is open to all, this factor does not necessarily operate to the advantage of one system over the others.

A second requirement for proper color rendition is color balance, a term that indicates that the brightnesses of the three primary-color images are in proper proportion. This is especially important when all three primaries are combined to produce a white (or nearly white) element in the picture. Unless the three primary images are in precise balance, the element intended to be white will exhibit a greenish, reddish, or bluish tinge (or other off-color tinge), depending on what primary (or what pair of them) is present in disproportionate brightness. Color balance is particularly important in reproducing the delicate tones of flesh color. A slight excess of green, for example, can transform a ruddy glow into a sickly pallor. Color balance requires the correct choice of camera color filters to accord with the receiver color primaries and with the lights used in the studio. It also depends upon the correct operation of the transmitter, the correct functioning of the receiver, and the correct adjustment of contrast. Here again these basic techniques of maintaining color balance can be used by all three systems, although there are differences in the ease with which it can be accomplished.

So long as the dots, lines, and fields occur in their proper places and in the proper sequence, and so long as the proper color balance is maintained, a high standard of color reproduction is possible in each of the proposed systems of color television. The observed differences in color fidelity are ascribable partly to poor color balance and partly to lack of registration (of dots, lines, or fields with minor effects due to color breakup and color fringing as described in section 10.

12. The addition of black-and-white detail to a color image

In color printing it is customary to employ four impressions, one in each of the primary colors, and the fourth in black (or dark brown). The black plate impresses shades of gray over the colors. One purpose of the black impression is to overcome an inherent shortcoming of the primary-color printing inks which, by themselves, are not able to represent as dark shades of gray as may be desired. Another purpose is to provide one impression (the black impression) which carries the basic pictorial detail of the subject, and thus relax to some extent the need for precise register among the three primary-color impressions.

This printing technique suggests that a similar method might be used in color television. If all the fine pictorial detail of a color-television image is presented in shades of gray, the detail of the primary colors may be allowed to be somewhat coarser without adverse effect on the over-all sharpness of the color image. This would allow an image of given sharpness to be sent over a narrower channel than would be required if the primary colors were sent in full detail and no gray image was employed.

Suppose then that the color image is to have a pictorial detail corresponding to 200,000 dots, equal to the detail of the present standard black-and-white image, and is to be sent at a field rate of 60 per second with conventional line interlace. Suppose further that all fine details having a width not greater than corresponding to two dots are transmitted only in shades of gray, wheras all details of width greater than two dots are transmitted in three colors. Then the fine detail in the gray image corresponds to frequencies from 2 to 4 megacycles and thus requires a video channel width of 2 megacycles, while each of the three primary-color images correspond to frequencies from zero to 2 megacycles and thus require three more video channels of 2 megacycles. The total video channel width is therefore 8 megacycles. By the method of dot interlace the three 2-megacycle color channels may now be interpersed and compressed. In the RCA form of the dot-interlace system the color channels are compressed into a single video channel from zero to 4 megacycles, or two-thirds of the sum of the three channels. This color dot signal is finally mixed with the fine detail gray signal and we have the entire picture signal occupying a video channel width of 4 megacycles, permitting it to be transmitted on a 6-megacycle radio channel. (A more detailed description of dot interlacing the color images and mixing them with the fine detail gray image is given in chapter 5.)

Hence, by confining the finest detail to shades of gray, and by using dot interlace, it is possible to compress a color transmission into the same channel now occupied by the black-and-white transmission, and to retain substantially the full detail of the image (200,000 dots) and the full flicker-brightness performance (60 fields per second).

The technique of transmitting fine detail in shades of gray only is known as the "mixed highs" system, from the fact that the highest

frequencies in the three color signals are mixed together before transmission to the receiver.

In the example given above, the dividing line between full-color transmission and gray-tone transmission was taken at a detail size equal to the width of two dots. The dividing line can be set at details considerably larger than this. In fact, in the RCA system, as described in chapter 5, certain practical shortcomings of the dot-interlace transmission process, currently embodied in the apparatus, reduce the detail transmitted in true color to items having the width of eight dots. Since there are some 420 dots or more to the line this still represents a very good color detail and no adverse effects are noted. Moreover, the shortcomings of the present apparatus in this respect are not fundamental and can be compensated rather exactly should the need arise.

The technique of transmitting fine detail in tones of gray is applicable only to the dot-sequential system of color television. It is not applicable to the line-sequential and field-sequential systems because these systems make no color distinction between the dots along any one line of the image. Hence, whatever detail is provided, as each line is scanned, must necessarily be provided in full to the particular color present in that line. Thus all three color images contain the fine detail, and there is no opportunity to confine the fine detail to a single (gray) image.

13. Relation of color service to existing black-and-white service

The principles discussed in earlier sections of this report refer to the intrinsic properties of sequential color systems which are rooted in the choice of scanning method. These properties determine the long-time utility of each system, since they are based on the fundamental attributes of human vision.

There are several additional properties of a less fundamental nature, but of great economic importance, which refer to the transition from the existing black-and-white service to the future color service. The problems of this transitional period will endure so long as both black-and-white and color transmissions are available in a given locality, and this situation may continue in many populous areas for an indefinite period. Accordingly the committee believes that the relative suitability of the color systems for public use must be judged, in part, in terms of their relation to the existing black-and-white service.

The transitional properties of the color systems are described by three terms—compatibility, adaptability, and convertibility—defined as follows:

Compatible color system.—A compatible color system is one capable of producing black-and-white images on existing black-and-white receivers without any modification of the receivers.[1]

Adaptable color system.—An adaptable color system is one in which existing black-and-white receivers can be modified to receive color transmissions in black-and-white.

[1] This definition was first advanced by the Joint Technical Advisory Committee in testifying before the FCC at the color hearing and adopted by the majority of those testifying thereafter. It is restricted to the rendition of color transmission on black-and-white sets as defined. Another form of compatibility, sometimes called reverse compatibility, relates to the reception of black-and-white transmissions on color receivers. Since the latter type of compatibility can be possessed by color receivers of all three systems to a nearly equal degree, and will undoubtedly be possessed by all color receivers manufactured during the transitional phase, the committee believes that reverse compatibility is not an important distinction between systems.

Convertible color system.—A convertible color system is one in which existing black-and-white receivers can be modified to receive color transmission in color.

In comparing systems on the basis of adaptability or convertibility, the cost, inconvenience, and technical complexity associated with the modifications are evidently important considerations. Comparative quantitative data on these aspects are at present inconclusive, in view of the rapid state of development of the systems, but it is possible to give a qualitative estimate of the relative adaptability or convertibility of each system.

The transitional properties of each system are stated in chapters 3, 4 and 5, and compared in chapter 6.

14. System characteristics

Those performance characteristics which are of paramount importance in comparing color television systems are—

(*a*) *Resolution.*—The amount of pictorial detail or the number of picture elements (dots) contained within the picture area. The greater the number of dots, the more copious the pictorial detail in the reproduced image.

(*b*) *The flicker-brightness relationship.*—The rate at which the successive fields are scanned determines the maximum brightness of the reproduced picture, above which flicker becomes objectionably apparent.

(*c*) *Continuity of motion.*—The number of fields presented per second must be high enough to permit motion in the image to be rendered in apparently continuous fashion.

(*d*) *Effectiveness of channel utilization.*—Since the space in the radio spectrum for television channels is severely limited by the needs of other services, it is of paramount importance to determine the relative effectiveness of the color systems in utilizing the 6-megacycle channel. The preceding sections have shown that the channel width is devoted to the performance characteristics above named; that is, adequate resolution, adequate brightness without flicker, and adequate continuity of motion. A system whose performance is inadequate in any of these aspects makes relatively ineffective use of the channel. In comparing two systems having equally adequate performance in one or two of these aspects, the system having superior performance in the remaining aspect or aspects is defined as making the most effective use of the channel. On this basis it is possible to compare the systems, on a qualitative basis, with respect to channel utilization.

The techniques for improving channel utilization include line interlace, dot interlace, the mixed-high method, and the use of long-persistence receiver screen materials to reduce flicker.

(*e*) *Color fidelity.*—Color fidelity is the degree to which the television receiver reproduces the colors of the original scene. It is particularly important that the system be capable of maintaining color fidelity over extended periods of time.

(*f*) *Defects associated with superposition of primary-color images.*—These defects include improper registration, color breakup, and color fringing.

(*g*) *Cost of color receivers.*—A final basis of comparison is the cost of a color receiver having adequate performance in each of the respects

listed above. While it is manifestly necessary to take this factor into account in arriving at a decision between the systems, the presently available cost figures are, in the opinion of the committee, not indicative of the situation to be expected when manufacture of receivers actually commences on a large scale. If, as seems probable, a tri-color tube is to be used in future receivers, no matter which system is adopted, the costs will be more nearly equal than if a rotating filter disk is used in one system (CBS), a three-tube dichroic-mirror receiver in another (RCA) and a triple-projection receiver in the third (CTI). In view of the fact that a definitive answer to the question of receiver costs cannot be available until the color service is actually instituted and large-scale production is under way, the committee believes that it will not be possible to take the relative receiver cost factors into consideration in arriving at the necessary policy decisions affecting color television.

In the following chapters these factors are related explicitly to the three proposed systems, and the apparatus used in each system is described as it relates to performance, complexity, and cost.

CHAPTER 3

THE CTI LINE-SEQUENTIAL SYSTEM

15. Introduction

The information on the CTI system, contained in this chapter, is based in part on the document "Written Comments of Color Television, Incorporated" dated August 25, 1949, submitted in evidence before the FCC hearing, and in part on verbal comments offered by representatives of CTI at the demonstrations of the system. The description is based on the system as demonstrated by CTI on May 17, 1950; namely, that using the so-called "interlaced color shift."

16. The CTI scanning pattern: How the picture is put together

Figure 1 illustrates the manner in which the CTI line-sequential color television image is scanned. The figure shows the scanning lines in the six fields required to make up a complete color picture. The lines are separated by blank spaces of equal depth. In the first field the topmost line (line 1) is scanned wholly in green, the next line below (line 3) wholly in blue, and the next line (line 5) wholly in red. As successive lines are scanned (lines 7, 9, 11, etc.) the sequence of lines in green, blue, and red is repeated until the bottom of the image is reached. This completes the scanning of the first field.

Thereafter the second field is scanned in the same manner, also covering lines numbered 1, 3, 5, 7, 9, etc. Line 1, this time is scanned in red, line 3 in green, line 5 in blue, and so on until the bottom of the second field is reached.

The third field is scanned next, again covering only the odd lines. This time line 1 is scanned in blue, line 3 in red, and line 5 in green, and so on until the last odd line of the field is reached.

The image has now been scanned in all three colors covering the odd lines only, and this process is then repeated for the even lines, which lie midway between the odd lines scanned in the first three fields.

In the fourth field the color sequence is as follows: line 2 is scanned in green, line 4 in blue, line 6 in red, and so on, down to the bottom of the field. For the fifth field the color sequence is line 2 blue, line 4

red, line 6 green, and so on, and finally in the sixth field the color sequence is line 2 red, line 4 green, line 6 blue, and so on.

All the lines have now been scanned in all three colors and a complete color picture has been produced.

The image consists of 525 lines, about 490 of which are visible on the viewing screen, and the fields are scanned at a rate of 60 per second. The radio channel width used is 6 megacycles, corresponding to a video band width of about 4 megacycles. These numbers are identical to those employed in the standard black-and-white system. Consequently the number of picture elements per line is the same as in the black-and-white system, about 420 picture elements per line. The maximum number of picture elements in the image, comprising 490 visible lines each with 420 dots, is about 200,000.

The whole sequence of color scanning is completed after six fields have been scanned, and the sequence then repeats. Since the field scanning rate is 60 per second, there are one-sixth as many, or 10, complete color pictures per second.

17. Essential equipment of the CTI system

Before discussing the performance of the CTI system, it is necessary to describe briefly certain essential items of equipment, unique to this system. These include the camera at the transmitter and the viewing apparatus at the receiver (picture tubes and viewing screen).

The CTI camera employs one image orthicon camera tube, of the type commonly used in black-and-white broadcasts. When used for black-and-white transmissions, one lens focuses the image on the sensitive plate of the camera tube. When used for color transmission a system of color-selective filters is used for producing three images side by side on the sensitive plate, one for each of the three primary colors.

The lenses are so positioned that they form three images on the sensitive plate, one beside the other in a horizontal row. These images appear in the three filter colors, and are arranged in the order red, green, blue, from left to right.

The three images are scanned, from left to right as a group, by sweeping a beam of electrons across the sensitive plate. As the beam sweeps it creates an electrical signal proportional to the values of light and shade along a particular line in each of the images. Consequently as the beam sweeps once across the group of images, it scans first a line in red, then a line in green, and finally a line in blue.

The beam then scans across the group of three images, along an appropriate path parallel to the first, and thereby produces three more lines in red, green, blue, and so on. This scanning process continues, each passage of the beam across the group creating three lines in the three primary colors, until the bottom of the group of images is reached. The beam has now scanned a complete field, corresponding to one of the scanning patterns shown in figure 1 and described in section 16.

The beam then returns to the top and the scanning process is repeated across the group of images. By properly adjusting the starting point of the scanning process in each successive field the color sequence is arranged to conform with the scanning sequence described in section 16 and illustrated in figure 1.

The signal created by the camera is transmitted to the receiver. Here the images are reproduced on the screen of a picture tube. The screen is composed of three different types of fluorescent material, arranged side by side, one material producing red light, another green light, and the third, blue light. The scanning beam in the picture tube moves over this three-part screen in exactly the same pattern as the beam in the camera and thereby recreates on the screen three images side by side, in red, green, and blue. These images are, therefore, replicas of the optical images focused on the sensitive plate of the camera tube.

The three primary-color images are combined by projecting them through three lenses onto a common viewing screen. Care must be taken, in the scanning of the camera and picture tube and in the positioning of the camera and projection lenses, to insure that these three images are precisely in register on the viewing screen. A reproduction of the original scene in color thereby appears on the projection screen.

If a black-and-white receiver, of the type commercially available in the United States, is tuned to a color transmission from a CTI color camera, a black-and-white image results. This follows from the fact that the CTI system operates with 525 lines, 60 fields per second, which are identical to the scanning rates of the standard black-and-white system. For this reason, the CTI system is known as a compatible system, i. e., a color-television system which will provide a black-and-white version of the color transmission on present-day black-and-white receivers, without requiring any change in the receiver.

18. Performance characteristics of the CTI system

On the basis of the foregoing description of the CTI system, we can examine its performance characteristics in accordance with the outline presented in chapter 2, section 14.

The first of these characteristics is resolution, section 14 (*a*). Since the scanning rates and channel width of the CTI system are identical to those of the standard black-and-white system, the number of picture elements per line is, in theory, the same in the two systems, namely about 420, and the number of lines visible in the image is also the same, about 490. Therefore the over-all resolution of the CTI and black-and-white systems are the same, about 200,000 picture elements.

These resolution figures are based wholly on the geometry of the scanning pattern, and take no account of other effects, such as improper registration and line crawl, which may reduce the effective resolution available in the CTI system, as discussed below.

The second performance characteristic is the flicker-brightness relationship, section 14 (*b*). Since the number of fields per second in the CTI system is 60, the same number as in the black-and-white system, the large-area flicker performance is approximately the same. The small-area flicker effects are accentuated by the fact that each line is scanned in any one primary color only 10 times per second. Moreover, two lines of the same color in any one field are separated by two other lines in different colors plus three blank spaces. These two effects together cause an apparent motion of the lines upward or downward in the picture, known as line crawl. In common with all flicker effects, line crawl becomes more pronounced as the image becomes brighter. Consequently this effect may in fact set the upper limit on the acceptable brightness of a line-sequential color image.

The phenomenon of line crawl is accompanied by an apparent grouping of the lines and this effect reduces the apparent vertical resolution below the value set by the scanning pattern geometry.

Interline flicker is also pronounced in the image produced in this system, particularly when a primary color is being transmitted, because each line is then illuminated only 10 times per second. If the image is bright, sharply defined horizontal edges exhibit a marked blinking effect.

The third performance characteristic, section 14 (*c*), is continuity of motion. So far as large-area portions of the image are concerned the continuity is determined by the field rate, so the performance is not noticeably different from that of the black-and-white system. On the other hand, the sharpness of edges of colored objects in motion is noticeably affected by the fact that the complete color sequence occurs at a rate of 10 per second, whereas the complete sequence in black-and-white images occurs at 30 per second.

The fourth characteristic, section 14 (*d*), is effectiveness of channel utilization. Here the principal shortcomings of the CTI system, as thus far demonstrated, are the impracticability of using dot interlace and the poor small-area flicker performance. If dot interlace were attempted, while the resolution would be doubled, the complete color-sequence rate would be lowered to 5 per second, thus greatly accentuating the small-area flicker effects.

The nature of the compromise necessary to fit the CTI system into the 6-megacycle channel can now be stated. The resolution and the large area flicker performance are maintained, so far as scanning is concerned, at the values of the black-and-white system, but to secure this performance in color it is necessary to lower the rate of the complete scanning cycle to 10 per second, one-third the value of the black-and-white system. Accompanying the lower scanning cycle rate are small-area flicker effects, notably interline flicker and line crawl.

The fifth performance characteristic is color fidelity, section 14 (*e*) On the assumption that proper fluorescent materials and color filter are used in the picture tube and proper color filters are used in the camera, the large-area color fidelity of the system suffers no limitation. Lack of registration, noted below, may affect adversely the color fidelity in small areas, particularly in the fine details and along the edges of brightly colored objects.

Superposition defects, section 14 (*f*), are limited to improper registration, since color breakup and color fringing are confined to the depth of one or two scanning lines. Faulty registration may appear in four independent ways: (1) Misadjustment of the camera optics may produce color images of different size, shape, or orientation on the sensitive plate of the camera tube; (2) the motion of the camera electron beam may not be uniform or not properly alined with the images; (3) the scanning at the receiver picture tube may not produce congruent and properly oriented images; and (4) the projection lenses of the receiver may not bring the images into correct superposition on the viewing screen.

Finally, the method of depicting fine detail, section 14 (*d*), in this system is to impose the fine detail on all three primary-color images. The mixed-highs system of transmitting fine detail only in shades of

gray cannot be used in the line-sequential system for the reasons outlined in section 12.

19. Summary

The essential attributes of the CTI line-sequential system are as follows:

(*a*) It is a compatible system, employing the same number of lines per picture and the same number of fields per second as the black-and-white system. This permits a black-and-white version of the color image to be reproduced on standard black-and-white receivers, without modification of the receiver.

(*b*) It achieves resolution and large-area flicker performance equivalent to the black-and-white system, but is deficient in apparent vertical resolution and small-area flicker performance.

(*c*) It is subject to registration difficulties.

(*d*) It does not employ the channel width effectively, since neither the dot-interlace nor the mixed-highs principle are employed.

Chapter 4

THE CBS FIELD-SEQUENTIAL SYSTEM

20. Introduction

The information in this chapter is based on the testimony submitted by the Columbia Broadcasting System to the FCC during the color-television hearing, and on demonstrations of the CBS system viewed by members of the committee prior to May 1, 1950.

21. The CBS scanning pattern

Figures 2 and 3 illustrate the manner in which the CBS field-sequential color-television image is scanned. In figure 2 is shown the conventional line-interlaced version of the system. Each picture consists of 405 lines, divided into two fields of 202½ lines each. The fields are scanned at a rate of 144 fields per second. As shown in the figure, all the lines in one field are scanned in blue, the next in green, and so on in the sequence red, blue, green.

After six successive fields have been scanned, every dot in the image has been scanned in all three primary colors. Consequently, the whole scanning sequence occurs at a rate one-sixth as great as the field-scanning rate, that is, 144/6=24 complete scanning cycles per second. The complete scanning cycle is termed a "color picture." The color-picture rate of the CBS system is, accordingly, 24 per second.

In the dot-interlaced version of the CBS system (fig. 3) each line is broken up into dots, all of the same primary color, with blank spaces of equal size between the dots. These blank spaces are filled in with dots of another primary color, on the next successive scanning of that line. Consequently, a given dot in the image is scanned in all three colors only after 12 consecutive fields have been scanned, and the complete scanning cycle occurs at a rate of 144/12=12 color pictures per second. The corresponding color picture rate of the CTI line-sequential system (sec. 16) is 10 per second, and that of the RCA dot-sequential system (sec. 26) is 15 per second.

22. Essential apparatus of the CBS system

The CBS color camera employs one image orthicon camera tube and one lens. Between the lens and the sensitive plate of the camera tube is located a filter disk containing six transparent filter segments, two for each of the three primary colors. The disk rotates at 1,440 revolutions per minute, so the filter segments move past the sensitive plate at a rate of 144 segments per second. The disk rotation is synchronized with the 144-per-second field-scanning rate of the camera. In this manner all the lines in one field are illuminated in red light, the lines of the next field in blue, and the lines of the third field in green, and so on, in the sequence red, blue, green.

These elements of the CBS camera are the same in the line-interlaced and dot-interlaced versions of the system. In the dot-interlaced version, the electrical output of the camera is rapidly switched on and off. The camera is thus effectively connected to the circuit during the scanning of a particular dot, and is disconnected during the scanning of the adjacent blank space, then reconnected for the next dot, and so on. The rate of connecting and disconnecting the camera is about 9,000,000 per second (9 megacycles).

Two types of receiver have been demonstrated by CBS. In the first a rotating filter disk, similar to that used in the camera, is positioned before the screen of the picture tube. This disk carries six filter segments, two in each of the three primary colors. The disk rotates at 1,440 r. p. m. and is synchronized with the 144-per-second field-scanning rate of the receiver. The image formed on the screen of the picture tube is displayed in white light, and this light, passing through the colored filters, takes on successively the three primary colors. Thus, the light emerging from the receiver is red on one field, blue on the next successive field, and green on the third, and so on. By means of synchronizing impulses, the position of the receiver filter disk is controlled so that red light is produced by the receiver only when the red filter is positioned before the camera tube at the transmitter, and similarly for the other two colors.

The system thus comprises two filter disks rotating in rigid synchronism, so positioned that the filters before the camera and the picture screen always have the same color at any instant.

It is not considered feasible to use a rotating disk with picture tubes exceeding about 12½ inches in diameter because of the physical size of the disk involved.

The second type of receiver is very similar to that used in the CTI system, described in section 17, chapter 3. A single picture tube is used, but three separate images are formed on the screen, one above the other, one in each of the primary colors. The blue-colored image is formed only during the fields scanned in blue by the camera, and similarly for the images in the other two colors. An optical system comprising three lenses projects the three images so that they fall, one on top of the other, on a common viewing screen. The scanning of the images, and the choice of lenses and positioning of the lenses with respect to the image, must be precisely controlled to preserve registration between the projected images. By using a green phosphor of comparatively long decay time this type of receiver eliminates practically all flicker and color break-up.